NASA Technical Memorandum 210258

Research and Technology

2000/2001 Report

John F. Kennedy Space Center

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Foreword

As the NASA Center of Excellence for Launch and Payload Processing Systems and launching space missions, the John F. Kennedy Space Center (KSC) is placing increasing emphasis on advanced technology development. KSC's dual mission includes spaceport and range technologies as well as space launch operations. To focus our technology development efforts, we have created a Spaceport Technology Center initiative with a portfolio of technology developments that will assist us in improving Space Transportation System safety, reducing the cost of access to space, and enabling greater commercial success of our space launch industry. Our technology development activities encompass the efforts of the entire KSC team, consisting of Government and contractor personnel working in partnership with academic institutions and commercial industry. This KSC Research and Technology 2000/2001 Report demonstrates these contributions to the KSC mission.

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Roy D. Bridges, Jr.
Director

CONTENTS

CONTENTS (cont)

CONTENTS (cont)

Technology Programs and Commercialization

Introduction

The John F. Kennedy Space Center's (KSC) outstanding record of achievements has earned it an honored place in history and an essential role in space transportation today. As NASA's Center of Excellence for Launch and Payload Processing Systems, KSC is increasing the momentum in space-faring technology development for current and future spaceports. The Spaceport Technology Center (STC) initiative carries out KSC's role within NASA to meet the goals of increased safety, reduced cost of space access, and rapid expansion of commercial markets by infusing spaceport technologies into all facets of recent and future Space Transportation Systems.

KSC's historic background as the nation's premier launch site creates an ideal environment for the STC. The STC's knowledge, expertise, facilities, and equipment provide technologies and processes to customers who propose to build and operate spaceports on Earth, in orbit, and beyond. The STC is composed of three strategic lines of business: Spaceport Operations, Spaceport Design and System Development, and Range Technology and Science. KSC has unparalleled expertise in designing, building, and operating a spaceport with all its complex systems.

The thrust of STC technology development activity is concentrated in six Spaceport Technology and Science Thrust Areas — Fluid System Technologies; Spaceport Structures and Materials; Process and Human Factors Engineering; Range Technologies; Command, Control, and Monitoring Technologies; and Biological Sciences. KSC's leadership in incorporating safer, faster, cheaper, and more robust systems and technologies will pave the way for future space industry. This report is organized by these six Technology and Science Thrust Areas.

KSC aggressively seeks industry participation and collaboration in its research and technology development initiatives. KSC also seeks to transfer its expertise and technology to the commercial sector and academic community. Programs and commercialization opportunities available to American industries and other institutional organizations are described in the Technology Programs and Commercialization Office Internet Web site at *http://technology.ksc.nasa.gov.* Additional insight into KSC's Spaceport Technology Center can be found on KSC's homepage at *www.ksc.nasa.gov.*

Fluid System Technologies

Fluid System Technologies cover the technology development for the fluid systems/infrastructure used for servicing existing and future space vehicles at the nation's spaceports. Areas of technology development include the production, storage, distribution, servicing, and disposal of current and future fluid needs. It also includes the ancillary equipment and subsystems that provide for the safe and efficient operation of these and Spaceport support systems. Space Transportation System disciplines covered are propulsion, power, thermal management, environmental control, life support, and fire suppression systems.

Activities/focus areas include the following:

- Storage, Distribution, and Servicing Systems
- Production, Recovery, and Disposal Systems
- Vehicle Interface Systems
- Safety Systems
- Expendable Launch Vehicle In-Flight Thermal/Fluids Environments and Management

The goals and objectives of Fluid System Technologies include the following:

- Reduce cost per pound of payload to orbit by decreasing the labor and materials cost of processing each mission (decreasing variable costs/flight operations, fixed costs, fluid systems parts count, and number of supporting systems)
- Increase safety by the replacement/reduction of hazardous operations and increased systems fault detection/corrective action automation, fluid systems reliability/dependability, and operator awareness/visibility

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Magnetic Impulse Force (MIF) Calculator

The pumping of liquid oxygen (LO_2 or LOX) by magnetic fields using an array of magnets is a current topic of research and development at KSC. In order to predict the total B-field and force from a solenoid magnet of radius *a* composed of *N* wraps of wire of diameter 2*b*, special-purpose software was developed. This report summarizes the software solution developed for KSC's Applied Physics Laboratory that was used to model the magnetic driving force circuit variables and the kinematics of LOX transport through a pipe.

The basic mathematical model consists of two primary parts. As shown in figure 1, the coil model includes the calculation of inductance and resistance, as well as the magnetic field and force generated by the coil. The second part of the model, shown in figure 2, includes the calculation of current, heat dissipated in the coil, and the time to maximum current. The coil is characterized by a computed resistance R and inductance L, which are dependent on coil geometry and wire properties. A driving impulse current is generated by charging a capacitor C to a voltage maximum of Vc, then throwing a switch to discharge the capacitor.

The kinematics of LOX transport is modeled by computing a recursive set of difference equations, representing the position and velocity of the LOX level by taking into account all forces on the LOX column. These estimates are updated every sample time based on the selected time step (t_step) and number of steps (M). An independent initial velocity can be specified to simulate the initial conditions imposed by stacking multiple driving coils.

The mathematical model consisting of the current, coil, and kinematics was programmed using Visual Fortran 90. The source code was then compiled as a Windows dynamic link library (DLL) so it could be interfaced with a separate Windows graphical user interface (GUI) (see figures 3 and 4). The GUI software was developed using LabView tools. It is compiled and may be executed on any machine using the freely distributed LabView run-time engine.

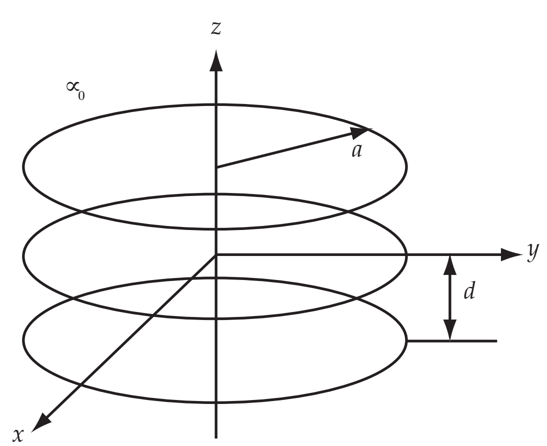

Figure 1. Coil Composed of Multiple Stacked Current Loops

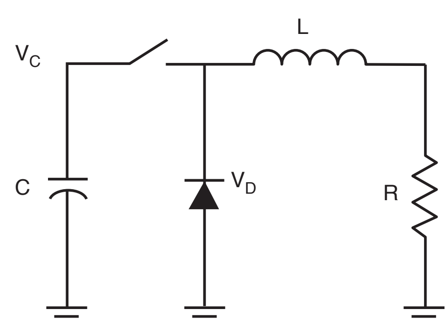

Figure 2. RCL Circuit Model of Impulse Current

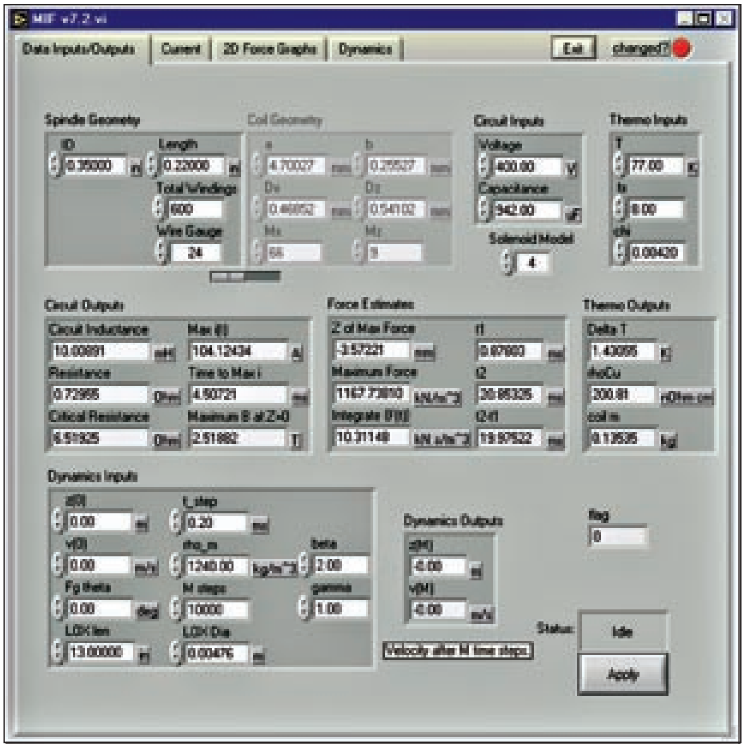

Figure 3. MIF Graphical User Interface

Key accomplishments:

- Developed the mathematical model of inductance, magnetic field and force, and circuit model of driving impulse current.
- Implemented this model as a Windows DLL object using Visual Fortran 90.
- Interfaced the DLL with a Windows GUI written under LabView.

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Participating Organization: Dynacs Inc. (Dr. C.D. Immer, Dr. J.E. Lane, and Dr. J.C. Simpson)

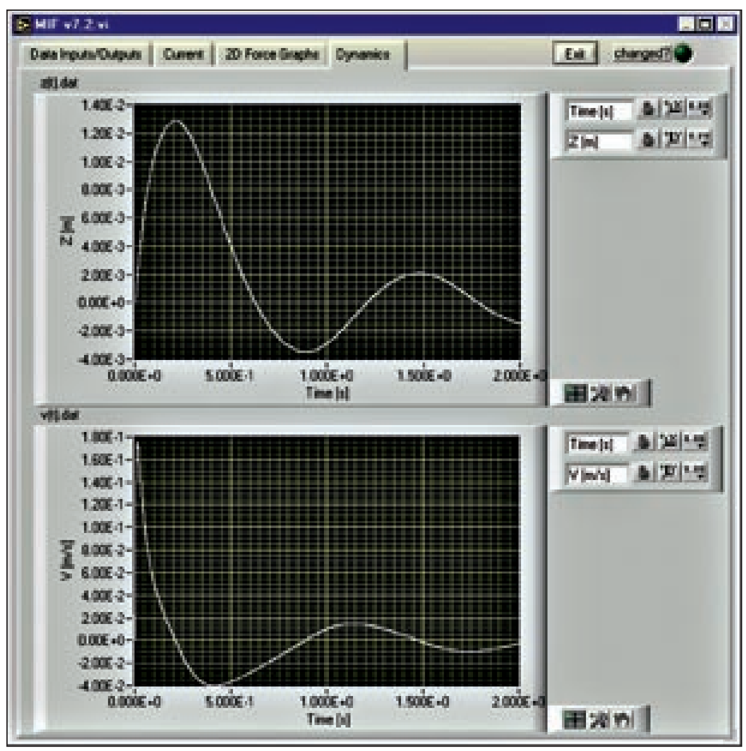

Figure 4. MIF Plots of LOX Level Position and Velocity

Transport of Liquid Oxygen With Magnetic Fields

The purpose of this study is to determine the effectiveness of using magnetic fields to move/pump liquid oxygen (LO_2 or LOX). It is well known that LOX has sufficient magnetic susceptibility that a strong magnetic gradient can lift it in the Earth's gravitational field. The question to be addressed is to what degree this phenomenon can be utilized in transporting (i.e., pumping) LOX not only on Earth, but on Mars and in the weightlessness of space. The primary goal of this study is to understand the magnetic transport of LOX so potential applications can be studied and assessments given.

The team developed two approaches to moving LOX with magnetic fields. The first concept is based on the magnetocaloric effect. This is a method of transferring fluid via a static magnetic field and a temperature gradient. It is clear that for an incompressible fluid placed in an arbitrary field there is no net force on the fluid integrated over all space. There must be some place where the symmetry is broken in order to get a nonzero net force on the fluid. To break this symmetry and elicit a net force (and consequently the net flow) from a static field, the temperature dependence of magnetic properties of

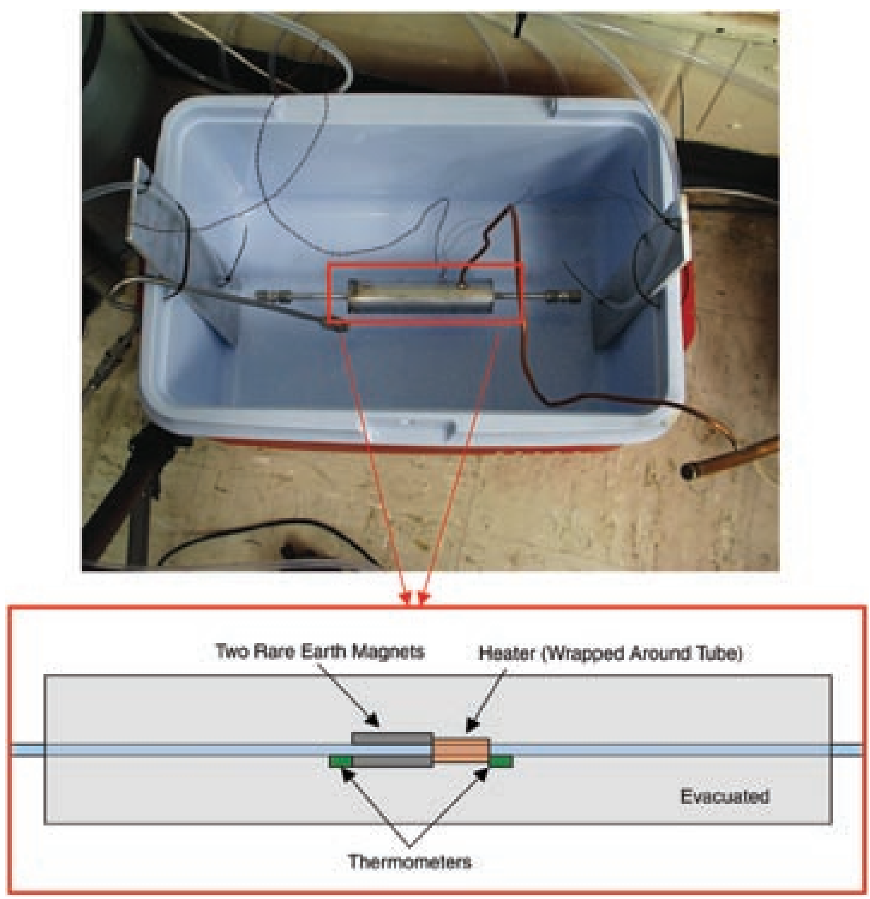

Figure 1. Magnetocaloric LOX Pump

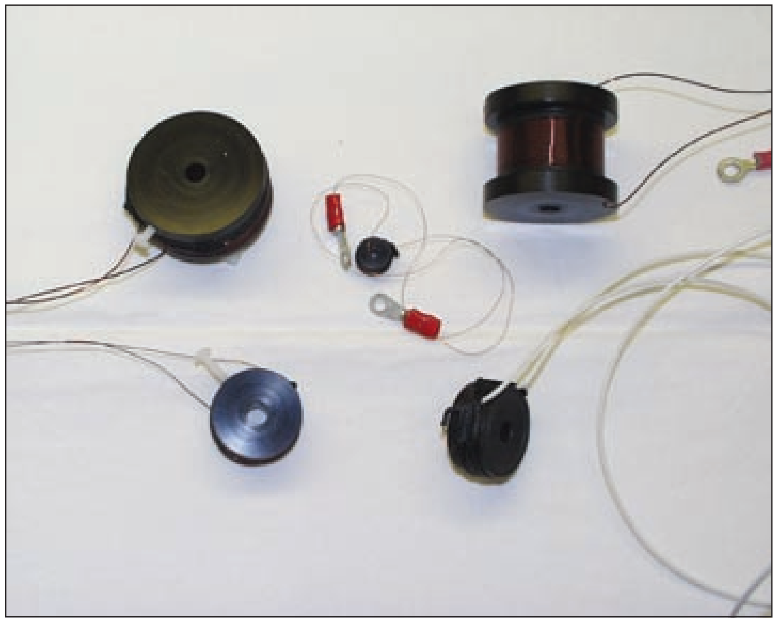

Figure 2. Assorted Coils for Pulsed Magnetic Field LOX Transport

the fluid can be exploited. Given an arbitrary magnetic field and a temperature gradient, there will be a net force whose direction and magnitude depend on the details of the temperature dependence of the magnetic fluid and the magnetic field profile. This method is a way of converting heat directly into motion – it is a heat engine. Figure 1 shows a prototype magnetocaloric pump.

The second method for transporting LOX is via pulsed magnetic fields. This method relies on access to the edge of a quantity of LOX. In this method, a finite amount of LOX is placed near one side of a series of concentrically spaced copper wire coils (each essentially an electromagnet). A quick pulse of a large amount of current (typically 200 amperes for about 10 milliseconds) draws the LOX toward the center of the first coil. At the time the LOX passes through the first coil, the current/magnetic field in that coil has gone to zero and a second coil fires in succession, drawing the LOX toward it. These ideas are similar to those developed for railguns and magnetic levitation (MagLev). In this manner with a series of pulsed coils, a finite globule of LOX may be transported down a tube. Figure 2 shows a few representative coils used in the pulsed magnetic field experiments.

Key accomplishments:

- Demonstration of magnetocaloric pumping (first time).
- Demonstration of movement of LOX with pulsed coils (first time).

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Participating Organization: Dynacs Inc. (Dr. C.D. Immer, Dr. J.E. Lane, J.C. Simpson, and Dr. M. Kandula)

Mars In Situ Resource Utilization (ISRU) Testbed

Several scenarios under consideration for a manned mission to Mars include using natural resources available on Mars to produce fuel and oxidizer for the return to Earth and oxygen for breathing air while on the surface. The preliminary goal is to demonstrate the ISRU technology prior to launching a manned mission. NASA at KSC is developing software to control the In Situ Propellant Production (ISPP) plant using a language developed at Ames Research Center. In support of the software development, KSC is also building an operating laboratory-scale production system to serve as a testbed (the ISRU Testbed) for evaluating the control software.

One of the chemical processes proposed for inclusion in ISRU is a well-known industrial process called a Reverse Water Gas Shift (RWGS) reaction. To support development of ISRU technology, KSC is building an operational laboratory-scale RWGS reactor that will demonstrate the RWGS process as well as evaluate the feasibility of controlling the plant with an autonomous controller. NASA at KSC is using a model-based reasoning language developed at the Ames Research Center to build the autonomous controller.

The ISRU Testbed is a laboratory-scale plant to produce water and oxygen using hydrogen and carbon dioxide as raw materials. On Mars, the carbon dioxide would be extracted from the Martian atmosphere and the small amount of hydrogen would be supplied from Earth. The hydrogen and carbon dioxide are reacted on a catalyst at high temperature in an RWGS process to create water and carbon monoxide. Electrolysis is then used to separate the oxygen and hydrogen from the water. Oxygen is used for breathing air or as an oxidizer in a bi-propellant fuel system. The hydrogen is recycled back to the RWGS process to produce more water. Ideally, recycling the hydrogen will allow a fixed amount of hydrogen carried from Earth to be used to produce an unlimited amount of water. The carbon monoxide is a waste product that in the laboratory is vented to a fume hood and on Mars is vented to the atmosphere.

In the ISRU Testbed, all the process variables (temperatures, pressures, flows, and gas composition) are instrumented electronically so the process can be controlled by the autonomous controller software. Process variables can be changed, and failure modes can be simulated to study both the normal and abnormal operation of the RWGS process. In addition, the RWGS process for oxygen production can be characterized and optimized for efficiency. On Mars, mass and power consumption are critical elements of any system; therefore, efficient operations and light weight are important considerations in building a flightworthy ISRU plant.

ISRU Reverse Water Gas Shift Testbed

Key milestones:

- May 2000: Initial operation.
- Oxygen production of 1 liter per minute.
- Operational characterization underway.

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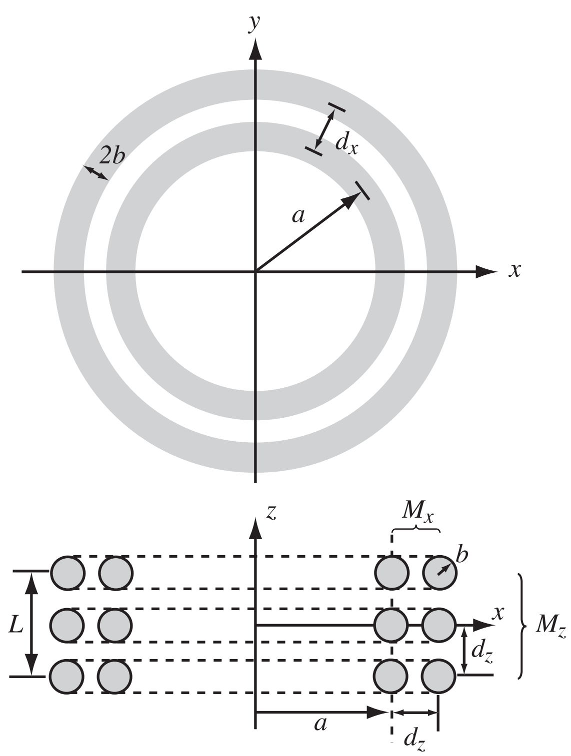
Solenoid Inductance and B-Field Calculator

The primary goal of this work was to devise a computationally efficient method of estimating the inductance of a solenoid that is arbitrarily shaped, composed of circular current loops, and not limited to a specific range of solenoid geometry values (see figure 1). The key algorithm employed in this work is the computation of all self- and mutual-inductance terms, since inductance is defined as the integral of the product of the current density and the magnetic vector potential, divided by the current squared. The resulting set of equations can be efficiently implemented in a high-level language such as C or Fortran in order to compute the total inductance of solenoids of arbitrary configuration.



Total Windings: $M = M_x M_z$

Total Length: $L = (M_z\text{-}1)\ d_z$

Figure 1. Solenoid Geometry Model

A common method of computing inductance of a solenoid in many engineering applications is to identify a handbook formula that most closely resembles the particular solenoid geometry at hand. Afterwards, when building the coil, a fine-tuning can be performed by adding or subtracting loops of wire.

For many applications, it is desirable to have a better method of estimating the inductance before reaching the build stage. That is the primary motivation for the Solenoid Inductance Calculator and its method of using magnetic vector potential for providing a more precise estimate of inductance that is not limited to a specific range of coil geometry values.

Four inductance calculations are performed, the first three of which are based on various handbook formulas. Model 4 is based on a first-principles approach in which the inductance is computed by means of a double summation of the magnetic field potential based on a circular wire loop.

The mathematical model, consisting of solenoid inductance and three-dimensional B-fields (B_x, B_z, and $|B|$), was programmed using Windows graphical user interface and linked as a Fortran Windows application (see figure 2). Magnetic field plots (see figure 3) are generated by writing the field components in the x-z plane (y=0), B_x, B_z, and $B=(B_x^2+B_z^2)^{1/2}$ to three output files and viewing with a general-purpose plotting package.

Key accomplishments:

- Derived a closed-form mathematical expression for inductance of a solenoid composed of any combination of concentric circular loops.
- Derived a closed-form solution for the three-dimensional B-field of a solenoid (see the table).
- Developed a Fortran Windows application to implement the solenoid inductance and B-field equations.

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Participating Organization: Dynacs Inc. (Dr. J.E. Lane, Dr. J.C. Simpson, and Dr. C.D. Immer)

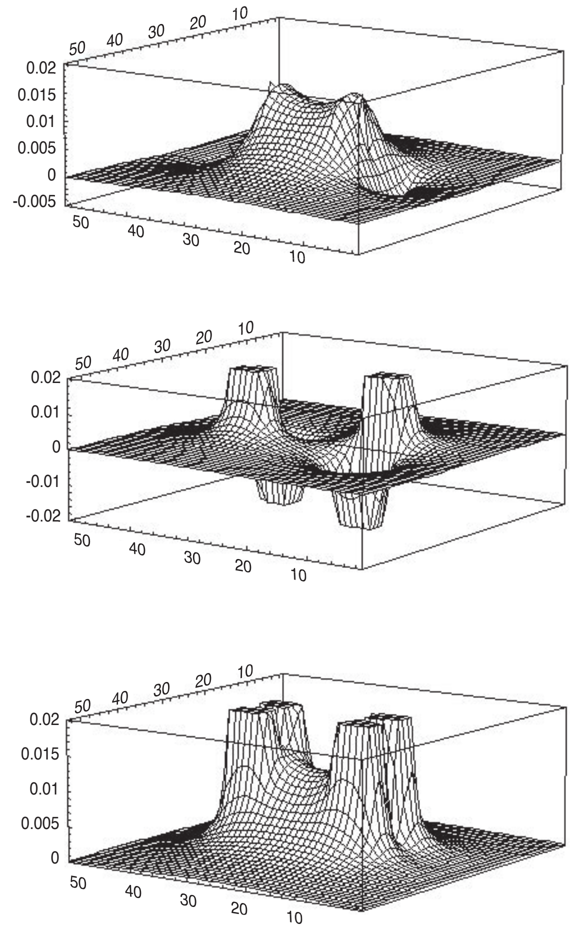

Figure 3. Solenoid B-Field Plots: Top, Bz(x,0,z); Middle, Bx(x,0,z); Bottom, |B(x,0,z)|

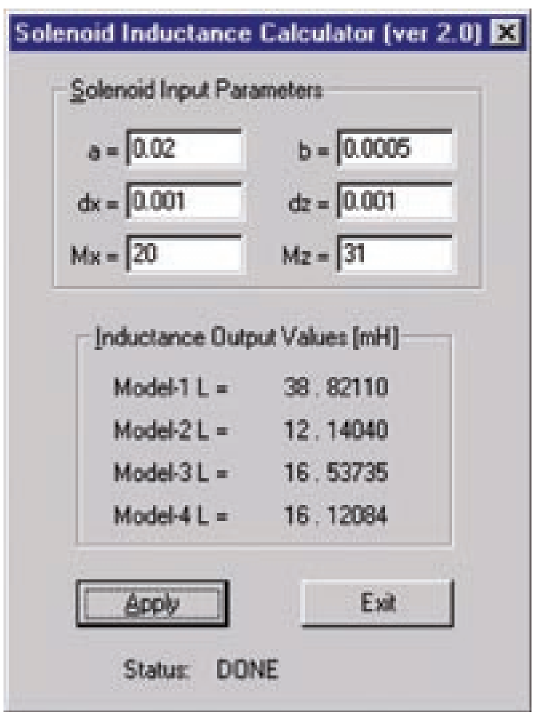

Figure 2. Solenoid Inductance and B-Field Calculator

Table 1. Circular Current Loop B-Field Formulas

$$B_x\,(x,y,z) = \frac{C\,x\,z}{2\alpha^2\,\beta\rho^2}\left[(a^2 + R^2)\,E\,(k^2) - \alpha^2 K\,(k^2)\right]$$

$$B_y\,(x,y,z) = \frac{C\,y\,z}{2\alpha^2\,\beta\rho^2}\left[(a^2 + R^2)\,E\,(k^2) - \alpha^2 K\,(k^2)\right]$$

$$B_z\,(x,y,z) = \frac{C}{2\alpha^2\,\beta}\left[(a^2 - R^2)\,E\,(k^2) + \alpha^2 K\,(k^2)\right]$$

$\rho^2 \equiv x^2 + y^2$, $R^2 \equiv \rho^2 + z^2$, $\alpha^2 \equiv a^2 + R^2 - 2a\rho$,

$\beta^2 \equiv a^2 + R^2 + 2a\rho$, $k^2 \equiv 1 - \alpha^2/\beta^2$, and $C \equiv \mu_0\, i/\pi$

Buffer Gas Acquisition and Storage

The Martian atmosphere consists mostly of carbon dioxide (95.5 percent), nitrogen (2.7 percent), and argon (1.6 percent). These gases are normally at pressures from 6 to 8 torr. Currently, there is a proposal to react hydrogen that would be transported to Mars with the atmospheric carbon dioxide in order to produce oxygen and methane. The oxygen would be available for use as a propellant or for use in life support. This production process is currently receiving a great deal of attention. The other atmospheric gases present, argon and nitrogen, would also be needed to serve as purge gases or to mix with oxygen to form breathing air. One of the concerns in doing this, however, is the anesthetic quality that argon can exhibit when used as a component in breathing air. Therefore, any separation system must be able to separate the three components to a satisfactory level. One method for doing this is through the use of membranes with selective permeability.

This study examined several membranes, measuring the permeation rates of the carbon dioxide, nitrogen, and argon. The conditions for this study were varied from -80 degrees Celsius to room temperature and 0.1 to 3 bar. The concentrations were measured using a gas chromatograph equipped with a thermal conductivity sensor. The tests were carried out in the testbed illustrated in the figure.

To date, the membranes have shown general trends. The first of these is increased selectivity at lower temperatures. The relative permeation rates also showed changes with temperature.

Key accomplishments:

- Design and construction of a testbed for the testing of membranes.
- Initial set of membranes tested showing increased selectivity at lower temperatures.

Key milestones:

- 2001: Design of a multi-membrane system to separate the Martian atmosphere into its components. Construction of a prototype multi-membrane system.
- 2002: Testing of the prototype system in the Mars atmospheric test chamber.

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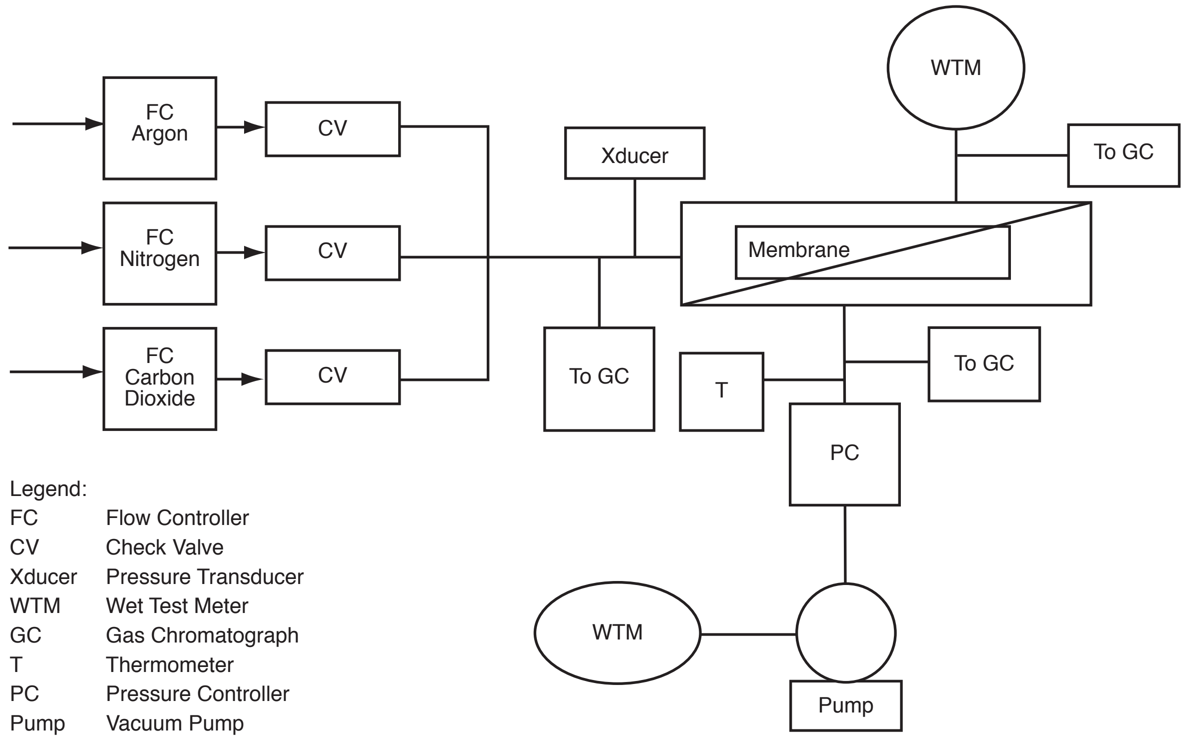
FC
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WTM
To GC
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To GC
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To GC
PC
WTM
Pump
Legend:
FC Flow Controller
CV Check Valve
Xducer Pressure Transducer
WTM Wet Test Meter
GC Gas Chromatograph
T Thermometer
PC Pressure Controller
Pump Vacuum Pump

Testbed

Mars In Situ Resource Utilization (ISRU) Oxygen Production

ISRU is one of the enabling technologies for Human Exploration and Development of Space (HEDS) missions. The atmosphere on Mars is nearly 95 percent carbon dioxide (CO_2), with negligible oxygen. For a HEDS mission to Mars, an In Situ Propellant Production (ISPP) plant is a key technology for manufacturing the oxygen required by a Mars ascent vehicle, surface power, and life support. CO_2 can be catalytically reduced by a variety of chemical processes such as the reverse water gas shift (RWGS) reaction and the Sabatier reaction (equations 1a and 1b). The subsequent electrolysis of water (equation 2), which is produced in each of these reactions, generates oxygen.

$$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O \text{ (Sabatier reaction)} \qquad (1a)$$

$$CO_2 + H_2 \leftrightarrow CO + H_2O \text{ (RWGS reaction)} \qquad (1b)$$

$$2H_2O \leftrightarrow 2H_2 + O_2 \text{ (water electrolysis)} \qquad (2)$$

Oxygen can also be obtained by the direct electrolysis of CO_2:

$$2CO_2 \leftrightarrow 2CO + O_2 \text{ (}CO_2\text{ electrolysis)} \qquad (3)$$

The direct electrolysis of CO_2 was studied using zirconia-based electrolysis cells. Zirconia is a ceramic material that becomes conductive at high temperatures and will transport oxygen ions through the molecular lattice under the influence of an applied electric field. At temperatures around 900 degrees Celsius (°C), substantial currents can be obtained, and CO_2 can be electrochemically reduced to oxygen. However, the very high temperatures of operation limit materials of construction to ceramics since most base metals are quickly oxidized at these temperatures with high oxygen concentrations. Moreover, zirconia is quite fragile to thermal or mechanical shock, particularly in the thin membranes used in these cells to lower the resistance and decrease resistive losses in the cell. Any crack in the membranes (multilayered cells are required for large-scale production) will result in contamination of the product oxygen with CO_2 or carbon monoxide. Such contamination would render the oxygen unsuitable for breathing air, one of its intended uses. The zirconia cell operates at about 1.6 volts, consuming about 50 percent more energy than theoretically required for this reduction.

A High-Pressure Electrochemical Reaction Chamber for Use With Liquid CO_2

In spite of the shortcomings associated with the zirconia electrolysis cells, the advantages of the direct electrolysis of CO_2 to generate oxygen are quite significant and, therefore, warrant further investigation and development. Numerous electrochemical systems can be envisioned to form the basis of a CO_2 electrolysis cell, and many of these systems operate at considerably lower temperatures than zirconia-based cells. Potentially applicable systems include molten salts, nonaqueous solvents, and low-temperature ionic conductors. Oxygen production in space cabins via the direct electroreduction of CO_2 using molten carbonate electrolytes was first considered in the 1960's. The molten carbonate system operates between 500 and 700 °C, which in itself represents a significant improvement of the zirconia system. Moreover, the molten carbonate electrolysis cell would be analogous to the molten carbonate fuel cell, a technology that is currently in full-scale production of high-throughput systems. Thus, many of the issues concerning materials of construction have already been addressed. There are, in addition, several viable approaches for performing room-temperature CO_2 electrolysis. Because of possible interfering reactions with proton reduction, aqueous systems do not readily accommodate the requirements for CO_2 electrochemical reactions. While these interferences can be circumvented by a variety of methods, nonaqueous solvents have a broader electrochemical window than the traditional water system, and such solvents [e.g., acetonitrile, propylene carbonate, and dimethyl sulfoxide (DMSO)] have been applied for CO_2 electrolysis. Moreover, CO_2 has a very high solubility in many of these solvents. In addition, there is a group of chemicals, the so-called ionic liquids (IL), that are essentially room-temperature molten salts. The high ionic conductivity, high solubility to many solutes, and broad electrochemical window make the IL's ideal for electrochemical applications.

CO_2 electrolysis is a heterogeneous process that requires the transport of CO_2 gas to a solid electrode. Even in traditional liquid-phase electrochemistry, gaseous CO_2 must first dissolve in the solvent and, even in the best solvent, the typical CO_2 concentration at standard temperature and pressure (STP) is less than 10 millimoles. The bulk concentration of CO_2 ultimately limits the rate of reaction. One unique approach to maximize the CO_2 concentration is to perform electrolysis directly on liquid CO_2. Liquid CO_2 is readily miscible in many of the nonaqueous and IL systems. At room temperature, CO_2 condenses at approximately 800 pounds per square inch and has a concentration of approximately 13 moles. Such high-pressure operation does require special apparatus for performing electrochemical operations (e.g., feedthroughs for electrodes and sample inlet and outlet ports). A custom-built test chamber was developed (see the figure) and used for evaluating the feasibility of liquid CO_2 electrolysis.

Key accomplishments:

- Set up and tested a molten carbonate electrolysis cell for CO_2 reduction at 600 °C.
- Evaluated numerous nonaqueous solvents for CO_2 reduction.
- Designed, built, and tested a high-pressure reaction chamber for evaluating electrochemical applications of liquid CO_2. Several nonaqueous solvent systems were screened for use in liquid CO_2.

Key milestones:

- Model and quantify the critical parameters that control sustainable CO_2 reduction.
- Down-select the most promising approach for scale-up.

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Participating Organization: Dynacs Inc. (Dr. W.J. Buttner and J.M. Surma)

Implementation of New Scrubber Liquor for Nitrogen Tetroxide Scrubbers That Produces a Commercial Fertilizer

NASA, in conjunction with Dynacs Inc. and United Space Alliance, has installed a prototype for the new scrubber liquor control system at the Launch Pad 39A oxidizer scrubber farm. The new system converts the nitrogen tetroxide (N_2O_4/NTO), the hypergolic oxidizer, into a fertilizer. The fertilizer produced is provided to the contractor who manages the citrus groves at KSC. This is Phase V of the project that seeks to comply with Executive Orders 12856 and 12873, the Right-to-Know Laws and the Recycling and Waste Prevention Law. Hypergolic propellants are used in spacecraft such as the Space Shuttle, Titan IV, Delta II, and other vehicles and payloads launched at KSC and Cape Canaveral Air Force Station. Monomethylhydrazine (MMH), N_2O_4/NTO, and hydrazine (N_2H_4/HZ) are the main propellants of concern. Fueling and deservicing spacecraft constitute the bulk of operations in which environmental emissions of nitrogen oxides (NO_X) occur. The scrubber liquor waste generated by the oxidizer scrubbers (approximately 311,000 pounds per year) is the second largest waste stream at KSC. The disposal cost for this oxidizer scrubber liquor waste is approximately $0.227 per pound or $70,600 a year.

The new process converts the scrubber liquor into a high-grade fertilizer. The process reacts N_2O_4 with hydrogen peroxide and potassium hydroxide to produce potassium nitrate, a major ingredient in commercial fertilizers. This process avoids the generation of the hazardous wastes, which occur when sodium hydroxide is used as the scrubber liquor. A patent application that covers the process has been filed with the U.S. Patent and Trademark Office.

The system was installed on Pad 39A in March 2000 and was used to support all the launches from this pad for the remainder of the year. During these support operations, several thousand gallons of fertilizer were produced that would have otherwise been hazardous waste. During the year a need was identified to actively control the concentration of the fertilizer being produced to eliminate the chance of precipitating potassium nitrate. This feature was implemented late in the year and has resolved the issue of precipitation. Also during this prototype implementation phase, other difficulties were encountered. These problems will result in an evaluation of the prototype and the addition of features to solve the problems before full implementation of the system continues.

Key accomplishments:

- Developed a method to eliminate the second largest waste stream at KSC (oxidizer scrubber liquor waste).
- Developed internal diagnostics that monitor the performance of the system.
- Developed a production process for potassium nitrate, a fertilizer currently used by KSC for use on lawns and citrus groves.
- Demonstrated that the process control system is robust and can with-

Oxidizer Scrubber Farm

stand field operations.

- Installed the system at the Pad 39A oxidizer scrubber farm.
- Supported three Space Shuttle launches using the new scrubber control system.
- Granted an exclusive license to a commercial company for the technology (it is pursuing its use at both foreign and domestic power plants).

Key milestones:

- Address the user needs for additional features.
- Test the new features before returning the prototype for implementation testing.
- Construct units for implementation at the remaining KSC sites.

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Participating Organization: Dynacs Inc. (P.H. Gamble, T.R. Hodge, P.W. Yocom, and S.L. Parks)

Spaceport Structures and Materials

Spaceport Structures and Materials include materials science and engineering and mechanical engineering skills, laboratories, and testbeds necessary for design, analysis, operation, and maintenance of a Spaceport's unique facilities, structures, and support equipment.

Activities/focus areas include the following:

- Launch Structures and Mechanisms
- Corrosion Science and Technology
- Electromagnetic Physics
- Nondestructive Evaluation

The goals and objectives of Spaceport Structures and Materials include the following:

- Ensure safe, efficient, and reliable structures techniques
- Enhance reliability and reduce maintenance cost of infrastructure
- Improve safety and reliability of operations through detection, mitigation, and prevention of electrostatic generation on equipment
- Participate in development of specialty materials in support of future structures and materials initiatives
- Improve safety of operations and reduce inspection costs

For more information regarding Spaceport Structures and Materials, please contact Karen Thompson, (321) 867-7051, *Karen.Thompson-1@ksc.nasa.gov;* Orlando Melendez, (321) 867-6379, *Orlando.Melendez-1@ksc.nasa.gov;* or Carlos Calle, (321) 867-3274, *Carlos.Calle-1@ksc.nasa.gov.*

Use of Computed Tomography (CT) for Characterizing Materials Grown Terrestrially and in Microgravity

The NASA/KSC Industrial CT system is tasked to determine noninvasively the density and composition characteristics at the mole fraction level of Earth-grown and microgravity-grown industrial-grade crystalline materials. Materials, such as mercury-cadmium-telluride used for infrared camera detectors, can be grown in the absence of gravity (on the Space Shuttle and eventually the Space Station) to a higher degree of purity than those grown on Earth.

The typical analysis of mole fractions of key elements that determine the integrity and quality of the crystal has been limited to invasive techniques such as electron dispersive spectroscopy (EDS). These techniques are time-consuming and worker-intensive. The NASA/KSC CT system produced viably similar results by making tomograms (slice pictures) of the materials. By applying techniques of relating mass attenuation coefficients to the CT data, mole fraction composition of key elements in the crystalline material can be determined. To date, the correlation of CT results as compared with the EDS technique has been very good.

Inspection of the OME

The use of CT for the task of determining crystal composition will greatly reduce the labor requirements (especially time) for analysis. In addition, the CT method is entirely noninvasive and leaves the sample intact. The crystal samples are made by melting the necessary materials in tube-type "furnaces" and allowing the subsequent solidification (crystallization) process to occur. This process was tested on Earth and on the Space Shuttle and, in the future, will be tested on the Space Station. A prime advantage of using CT for the analysis is that the material does not need to be removed from the furnace.

The CT system uses cobalt-60, a near monoenergetic energy source of about 1.25 megaelectrovolts (MeV) to penetrate the subject scanned. Then by methods similar to the medical "CAT" scanners, it acquires data and reconstructs an image of a thin cross section of the object. There is virtually no spatial (geometric) distortion in the resultant image as always found in conventional radiography or even digital radiography. Since spectral effects of the data acquisition are low by using the cobalt source, the accuracy of a correlation of image data (pixels) and true material density is remarkably good. From this correlation, the various mole fractions of elements involved and their location in a melt can be deduced. A CT inspection of a crystal melt encompasses the entire axial extent, which may be a rod of about 1-centimeter diameter and 10 to 20 centimeters long. CT data is acquired in contiguous slices (for example, every 1 millimeter along the crystal axis). This project is ongoing and is funded under the NASA-98-HEDS-05 program for the next 3 years.

The NASA/KSC CT system was also tasked to perform numerous noninvasive inspections of materials and systems associated with the aerospace program. Objects as small as a watch and as large as the orbital maneuvering engine (OME) have been inspected for part fit and material integrity. The accompanying figures of an OME illustrate such an inspection. Shuttle tires, tiles, switches, relays, hydrogen tanks, external tank quick disconnect valves, "pogo" fuel lines, OMS motor valves, and numerous non-Shuttle objects have been inspected since the CT was first tasked to service in 1985. While originally devised as a nondestructive engineering tool for flaw detection, the CT has far exceeded its intended use by being able to accurately provide internal dimensional and density analysis for material components and their composition.

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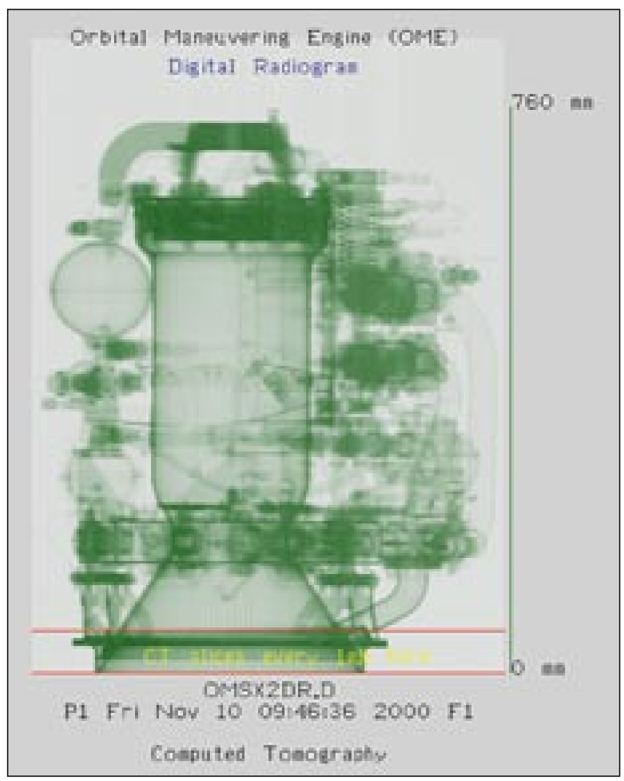
Participating Organization: Wyle Laboratories, Inc. (H.P. Engel)

CT Slice of OME Near the Exit Nozzle



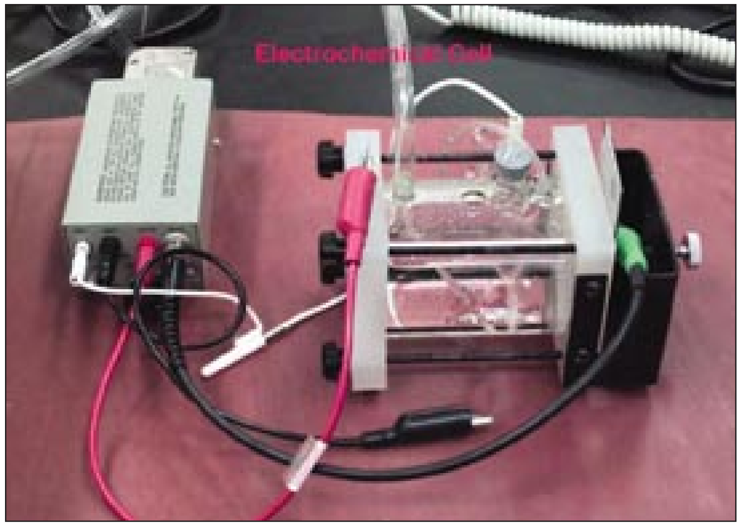
OME Digital Radiogram

Development of Volatile Organic Compound Compliant Primerless Silicone Coatings for Corrosion Control

NASA and other international space organizations face the difficult challenge of protecting launch pad structures from corrosion. Thin-gage steel and aluminum structures, such as protective bellows around drive mechanisms, flex repeatedly and consequently require highly flexible and adherent coatings. The aerospace industry has traditionally used paints having high volatile organic compound (VOC) content for protecting vehicles and support structures. State-of-the-art flexible paints employ solventborne rubber binder resins, which render the products highly viscous and difficult to apply by spraying. Silicone-based paints are formulated to yield temperature- and weather-resistant coatings that prevent corrosion by forming effective electrolyte barriers. However, silicones are normally delivered from organic solvents and exhibit poor adhesion to unprimed metals.

Formulation of anticorrosion paints from silicone dispersion, stabilized with novel polymeric surfactants and pigmented with nontoxic anticorrosive additives, may be the solution to the limitations of conventional silicone coatings. The latter silicone-modified polymers yield emulsions that strongly adhere the coating to metal surfaces. By forming a topcoat-bound primer layer in situ, low-VOC coatings having simple application properties and outstanding corrosion resistance can be formulated. Dispersions based on silicones and polymeric surfactants should have significantly lower emissivity than conventional waterborne and solventborne products.

Electrochemical Instrumentation



Electrochemical Cell for Coating Characterization

Successful development and continued optimization of primerless silicone paints that provide increased levels of performance while minimizing VOC's can benefit NASA's missions by combating corrosion on both aerospace vehicles and launch equipment. Commercial patents from this technology would enhance KSC's ability to attract industry partners for similar corrosion control applications.

The newly developed VOC-compliant primerless silicone coatings for corrosion control are currently being characterized at the KSC Corrosion Technology Testbed Facilities. The tests involve exposure at the outdoor corrosion test site and investigation of the corrosion prevention mechanism by electrochemical techniques in the corrosion laboratory.

Key accomplishments:

- Phase I: Developed a formulation that yielded the best adhesion and corrosion-inhibiting properties. Identified and tested new waterborne binder resins, corrosion inhibitors, and additives to improve the coating properties. The coating was reformulated to yield tougher coating films while preserving the desirable adhesion, sprayability, flexibility, dry time, and corrosion inhibition exhibited by the starting formulations. The new formulation was used to prepare coated metal panels for outdoor testing at KSC.
- Phase II: Advanced and refined the waterborne silicone coating technology developed in Phase I into a commercially viable family of coating products for providing long-term corrosion protection for ferrous and nonferrous metallic substrates. The ultimate goal was to provide an effective, environmentally sound method for protecting aluminum and steel surfaces in a harsh marine environment without introducing additional pretreatment and priming steps.

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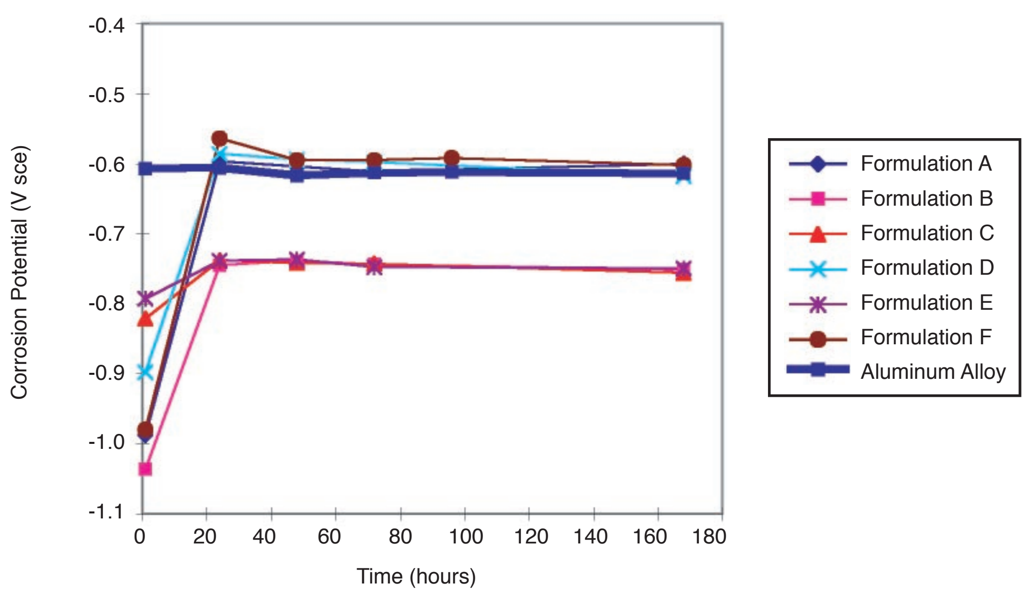
Participating Organization: Cape Cod Research (F. Keohan)

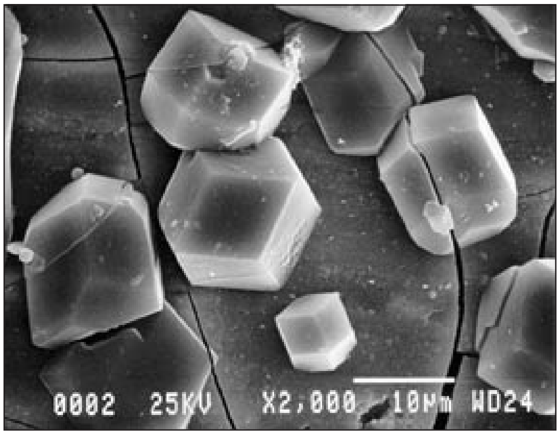
Characterization of Molybdate Conversion Coatings for Aluminum and Its Alloys

Chromate conversion coatings have been used for the protection of aluminum alloys for over 70 years. Although their efficiency in minimizing corrosion attack is excellent, there are health and safety concerns over their use because of their toxicity and carcinogenic nature. NASA at KSC has used chromate-based coatings on many of its spacecraft and desires to replace these harmful chemicals with safer coatings. Despite an extensive research effort over the past decade, a completely satisfactory replacement for chromate conversion coatings has yet to be identified.

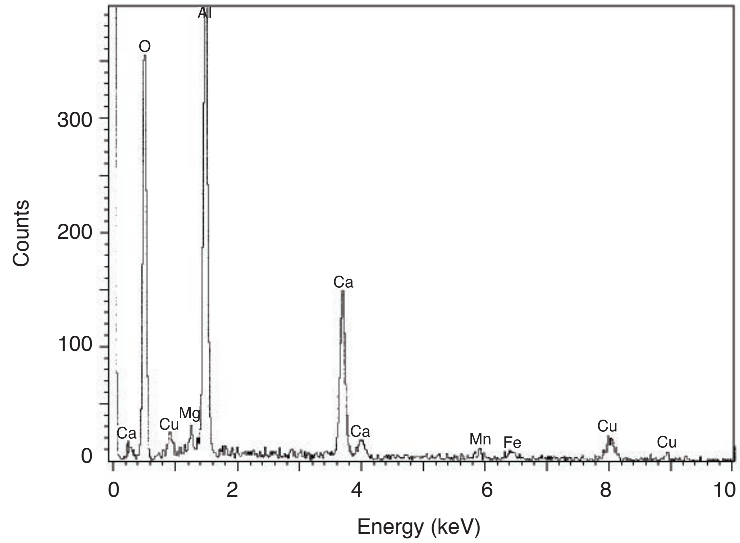
An environmentally friendly aluminum coating for Government and industrial applications resulted from collaboration between Lynntech, Inc. of College Station, Texas, and KSC. Lynntech participated with KSC's Labs and Testbeds Division under a Small Business Innovation Research (SBIR) contract to develop a molybdate-based conversion coating for aluminum and aluminum alloys. This innovation, referred to as Molyseal, is important because it contains molybdate instead of chromate. Molybdate mimics chromate in many of its applications, but it exhibits significantly lower toxicity. Tests demonstrated an exceptional corrosion protection by the new coating prepared from formulations consisting of molybdates and several additives. Some Molyseal coatings outperformed the chromate-based conversion coatings in electrochemical corrosion-resistance tests and passed a standard 336-hour salt fog test. These results established a sound technical feasibility for this new molybdate conversion coating. Lynntech applied for several patents relating to this technology and formed an alliance with multiple industrial partners in the metal finishing industry. Since Lynntech is a technology innovation and develop-



Corrosion Potential as a Function of Immersion Time in 5-Percent NaCl



SEM Micrograph of Corrosion-Coated (Formulation A) Aluminum Alloy



EDS Spectrum of Conversion-Coated (Formulation A) Aluminum Alloy

ment company, its goals are to move this innovation to the precommercial stage, secure appropriate patents rights, and then license the technology to an interested manufacturer for entry into the commercial sector.

Six proprietary formulations of the Moly-seal coatings on aluminum alloy 2024-T3 were characterized in the Corrosion Technology Testbed, Labs and Testbeds Division, by Electrochemical Impedance Spectroscopy (EIS), Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS), and X-Ray Photoelectron Spectroscopy (XPS).

EIS was used to investigate the corrosion-inhibiting properties of the molybdate conversion coatings on aluminum alloy 2024-T3 under immersion in aerated 5-percent sodium chloride (NaCl). Corrosion potential and EIS measurements were gathered for six formulations of the coating at several immersion times for 2 weeks. Nyquist as well as Bode plots of the data were obtained. The conversion-coated alloy panels showed an increase in the corrosion potential during the first 24 hours of immersion that later subsided and approached a steady value. Corrosion potential measurements indicated that formulations A, D, and F exhibit a protective effect on aluminum 2024-T3. The EIS spectra of the conversion-coated alloy were characterized by impedance that is higher than the impedance of the bare alloy at all the immersion times. The low-frequency impedance (Z_{lf}) [determined from the value at 0.05 hertz (Hz)] for the conversion-coated alloy was higher at all the immersion times than that of the bare panel. This indicates improvement of corrosion resistance with addition of the molybdate conversion coating. SEM revealed the presence of cracks in the coating and the presence of cubic crystals believed to be calcium carbonate. EDS of the test panels revealed the presence of high levels of aluminum, oxygen, and calcium but did not detect the presence of molybdenum on the test panels. XPS indicated the presence of less than 0.01 atomic percent molybdenum on the surface of the coating.

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Participating Organization: Lynntech, Inc.

High-Temperature Polyimide Foams, Cell Surface Area, and Flame Retardancy

Aromatic polyimides have been used for applications in the aerospace and electronics industries. Unique properties, such as thermal and thermo-oxidative stability at elevated temperatures, chemical resistance, and mechanical properties, are common for this class of materials. Newer to the arena of polyimides is the synthesis of polyimide foams. These polyimide foams were developed by Langley Research Center for high-performance applications like the Reusable Launch Vehicle (RLV) program. Because of a polyimide's high operating temperature (approximately 260 degrees Celsius) and cryogenic insulation properties, structural polyimide foams can potentially reduce the amount of Thermal Protection System (TPS) integration structure that is required on an RLV and the total amount of TPS required. The reduction in the TPS integration structure would reduce the total weight of and cost to build an RLV. This would allow the maximum payload weight to increase and make the vehicle more efficient for commercial applications.

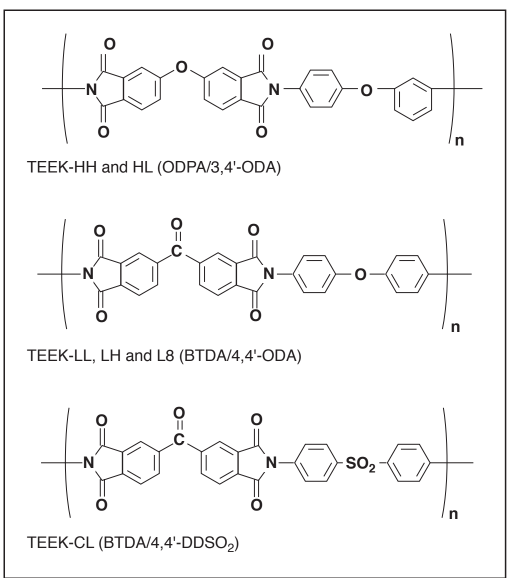

Figure 1. Chemical Structures of Foams

It is also essential to the development and application of new materials for the next-generation vehicles to understand their fire performance (fire performance is always a significant concern at KSC). In this research partnership, three different, closely related polyimide foams are comparatively studied, including thermal, mechanical, surface, flammability, and degradation properties. Although polyimide properties were studied previously, the data relates to films and not to foams. Foams have much more surface area and present a greater challenge to fire retardancy. Understanding degradation and properties (such as flame retardancy) versus structure (foam versus solid) is fundamental to pioneering research into polyimide foams and polymeric foams in general. Subtle differences in structure, varying densities, and cell surface area are researched to establish correlations to flame retardancy. Data gained from this research reveals vital information involving foam technology and flame retardancy.

Chemical structure, densities, and cell surface area versus flammability data are reported to validate the high performance of these materials. Other research indicated these materials can endure the rigors of space and space-like environments. Flammability results indicate these materials are well suited for extremely combustible environments and will maintain dimensional stability during exposure to high temperature and flames. Those properties also make these materials top candidates for the aircraft and fire-resistant building materials industries.

The flammability properties were characterized using ignitability (NASA-STD-6001 and ASTM G72), Radiant Panel (ASTM E162), Oxygen Index (ASTM D2863), Cone Calorimetry (ASTM E1354), and LOX Mechanical Impact Testing (ASTM D2512). Stability and degradation of the foams are being especially studied using the elevated temperatures of the Radiant Panel and the Cone Calorimeter.

The structures seen in figure 1 indicate only subtle differences in chemical composition among the three polymers. The table provides chemical names and densities of the different materials studied.

The percentage of shrinkage and the charring phenomena of the different foams reveal differences. It shows that density and chemical structure play a role, but importantly, cell surface area appears to play the greatest role in the shrinkage, as observed in TEEK-HL [0.032 gram per cubic centimeter (g/cm^3)] versus TEEK-HH (0.082

Table 1. Foam Densities and Descriptions

Foam, Density (g/cm^3)	Description
TEEK-HH (0.082)	ODPA/3,4'-ODA (4,4 oxydiphthalic anhydride/3,4-oxydianiline)
TEEK-HL (0.032)	ODPA/3,4'-ODA (4,4 oxydiphthalic anhydride/3,4-oxydianiline)
TEEK-L8 (0.128)	BTDA/4,4'-ODA (3,3,4,4-benzophenenone-tetracarboxylic dianhydride/4,4-oxydianiline)
TEEK-LH (0.082)	BTDA/4,4'-ODA (3,3,4,4-benzophenenone-tetracarboxylic dianhydride/4,4-oxydianiline)
TEEK-LL (0.032)	BTDA/4,4'-ODA (3,3,4,4-benzophenenone-tetracarboxylic dianhydride/4,4-oxydianiline)
TEEK-CL (0.032)	BTDA/4,4'-DDSO_2 (3,3,4,4-benzophenenone-tetracarboxylic dianhydride/ 4,4-diaminodiphenyl sulfone)

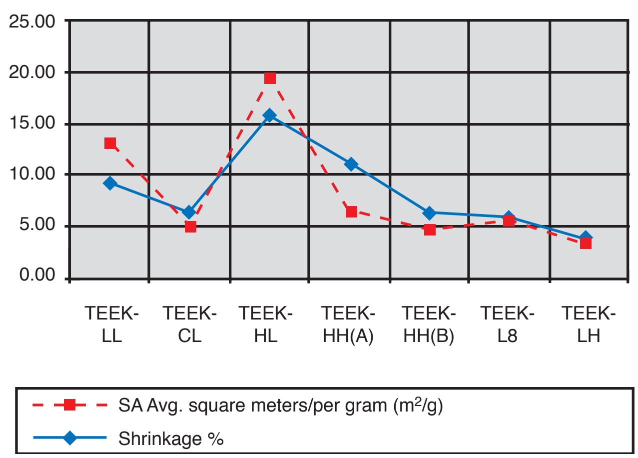

Figure 2. Surface Areas of Foams Versus Percent Shrinkage

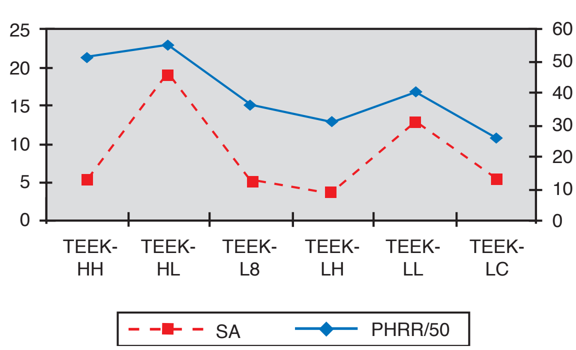

Figure 3. Surface Areas of Foams Versus Peak Heat Release Rate at 50 Kilowatts per Square Meter (kW/m^2)

g/cm^3). (See figure 2.) When comparing cone calorimetry data (peak heat release rate) and cell surface area, a qualitative correlation is also observed in figure 3. When comparing foams of the same densities but with subtle differences in chemical structure, the greater cell surface area TEEK-HL exhibits significant shrinking and degradation over TEEK-LL or TEEK-CL. For foams of similar chemical structure and thus similar average rates of heat release, cell surface area assumes a dominant role in fire performance.

Because of the intrinsic flame-retardant properties of polyimides, this research has given insight into the direct correlation of chemical structure, surface area, and flame retardancy of foams.

Key accomplishments:

- First polymer developmental research alliance between KSC and a NASA research center (under the auspice of the Dryden Memorial Fellowship). This collaborative research effort also includes national and international experts from NASA and academia.
- Revelation of fundamental information involving foam technology and fire retardancy, labeling the research as pioneering in nature.
- Presentation and publication with the American Chemical Society in 2000, including a book chapter on fire and polymers.

Key milestone:

- Several more publications are scheduled for the next year, including international publications.

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Participating Organizations: Langley Research Center (E.S. Weiser), Florida Institute of Technology (G.L. Nelson and J.R. Brenner), and White Sands Test Facility (J. Haas)

Electrostatic Properties of Materials in a Simulated Martian Environment

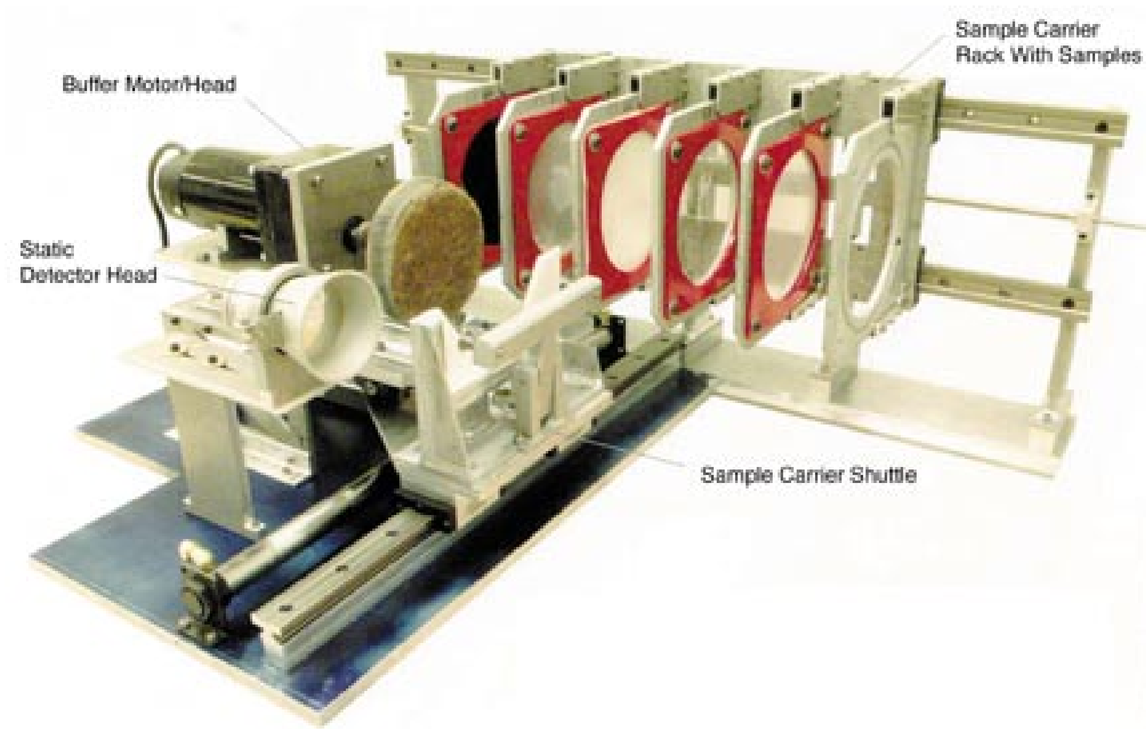
The Electromagnetic Physics Laboratory is engaged in experiments to learn about the electrostatic properties of materials exposed to the Martian regolith. Several techniques are currently being used to measure the generation of electrostatic charge by contact or friction between Martian regolith simulant particles and several insulating materials.

Potential problems regarding the generation of static charge on some materials stem from the composition of the Martian soil and from the absence of significant amounts of water on the surface or in the atmosphere of the planet. The surface of Mars is covered with a thin layer of fine dust particles of only a few microns in diameter. Particles of this size pose special problems because they have increased mobility when transported by the wind, which can reach speeds of 30 meters per second. Electrostatic charges can be generated when these fine particles are in contact with solid surfaces.

The project was initiated in March 1998. A 40-inch-diameter by 60-inch-long vacuum chamber was acquired in April 1998 and was modified for KSC's experimental needs. The chamber operation was completely automated during the summer of 2000. A robotic tester was designed to operate remotely in the vacuum chamber and is in its final stages of development. A remotely controlled linear rubbing machine was constructed and is in operation. A Martian regolith soil simulant was obtained from Johnson Space Center to research the possible electrostatic charging of Martian sands. The soil simulant was prepared from volcanic ash from the Pu'u Nene cinder cone on the island of Hawaii. Consequently, a prototype was designed and built for the soil simulant delivery system. An improved dust delivery system was designed and recently received by KSC's laboratory. This system simulates the Martian atmospheric movement of the dust particles to determine if there is electrostatic charge generation on selected materials. The research efforts in the upcoming year will focus on mathematical simulation and analyses of the interaction of moving dust particles and stationary surfaces, experimental studies of these interactions, testing of the materials selected for future Mars missions, and testing of the simulant soil and materials at ambient conditions as well as in the Martian environment.

Key accomplishments:

- Designed and fabricated Mars simulation chamber.
- Procured and upgraded the vacuum chamber.
- Performed total integrated automated control of the vacuum chamber operation.
- Obtained and analyzed the Martian regolith soil simulant.
- Built and tested the first proof-of-concept prototype and improved the system for soil simulant delivery.
- Completed the robotic tester and linear rubbing machine.



Electrostatics Robot

- Participated in the design of the Mars Environmental Compatibility Assessment (MECA) electrometer.
- Obtained a joint patent with the Jet Propulsion Laboratory for a unique electrometer design.
- Presented several papers at the following conferences and journals:
  - Journal of Electrostatics
  - Annual Meeting of the American Physical Society
  - Meeting of the Aerospace and Test Measurement Division of the Instrumentation, Systems, and Automation Society
  - Institute of Electrical and Electronics Engineers (IEEE) Aerospace Conference
  - NanoSpace 2000

Key milestones:

- Mathematical simulation and analyses of moving dust particles.
- Experimental studies of these interactions.
- Testing of the materials selected for future Mars missions.
- Testing the simulant soil and materials at ambient conditions as well as in the Martian environment.

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Participating Organizations: Florida Institute of Technology (Dr. J. Mantovani), Jet Propulsion Laboratory (Dr. M. Buehler), Swales Aerospace (Dr. C. Buhler), Wilkes University (A. Linville), YA-F2-T (Dr. R.H. Gompf and E.E. Groop), and YA-F1-T (D.C. Lewis and P.F. Richiuso)

Electrostatic Properties of Lunar Dust

Data from the Apollo program and recent lunar missions indicate electrostatic charging and discharging phenomena take place on the Moon. A horizon glow roughly 1 meter above the surface of the Moon was detected by Surveyor 5, 6, and 7 and more recently by the Clementine spacecraft. Experiments on Apollo 17 detected evidence of horizontal dust transport on the lunar surface. Dust dynamics such as these are thought to be the result of electrostatic charging of the dust particles created by their interaction with the photoelectron layer above the lunar surface.

Electrostatic charge is transferred between two surfaces whenever a contact potential exists between the surfaces. As the surfaces separate, the charge is driven back across the interface to prevent the potential from increasing. The maximum charge that can be acquired by an isolated surface is limited by electrical breakdown. The potential at which electrical breakdown occurs, as given by Paschen's law, depends on the pressure of the medium in which the solids are embedded. At the high-vacuum conditions of the lunar environment, this potential could be large for certain separation distances.

The Electromagnetic Physics Laboratory is currently studying the extent to which electrostatic charge can be generated and how it can accumulate on the lunar soil and dust particles. Lunar simulant samples prepared by Johnson Space Center from a volcanic ash deposit near Flagstaff, Arizona, were received in KSC's laboratory. A scanning electron microscope analysis of this simulant was performed to characterize its composition. The simulant was exposed to high-electric fields under extreme low-humidity conditions to obtain values for its Gauss limit and to study its discharge characteristics. A typical decay curve is shown in figure 1. Charge-to-mass

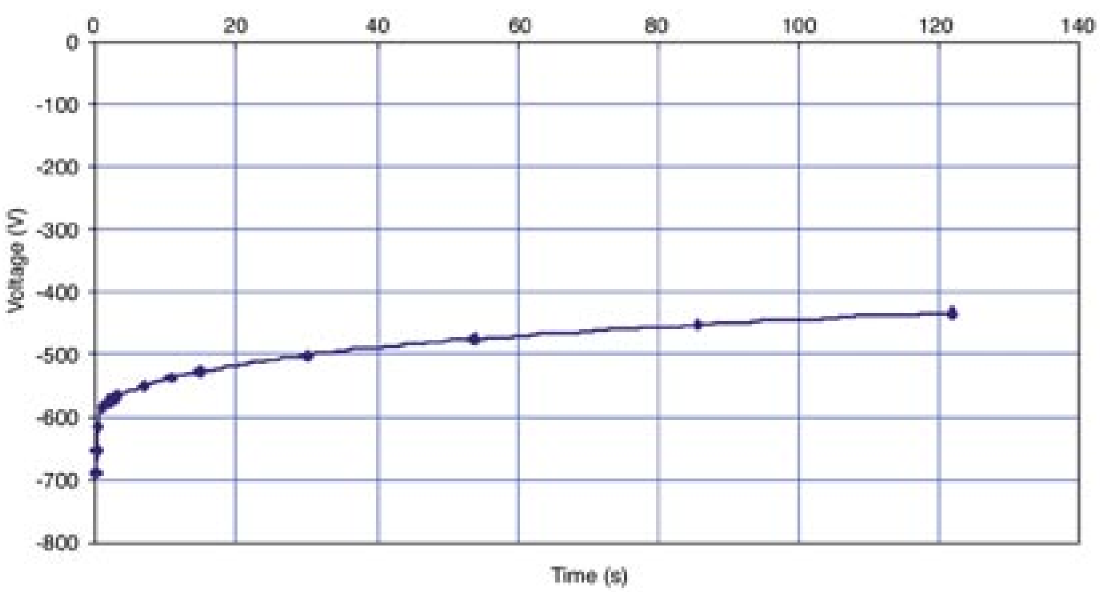

Figure 1. Charge Decay for Lunar Soil Simulant

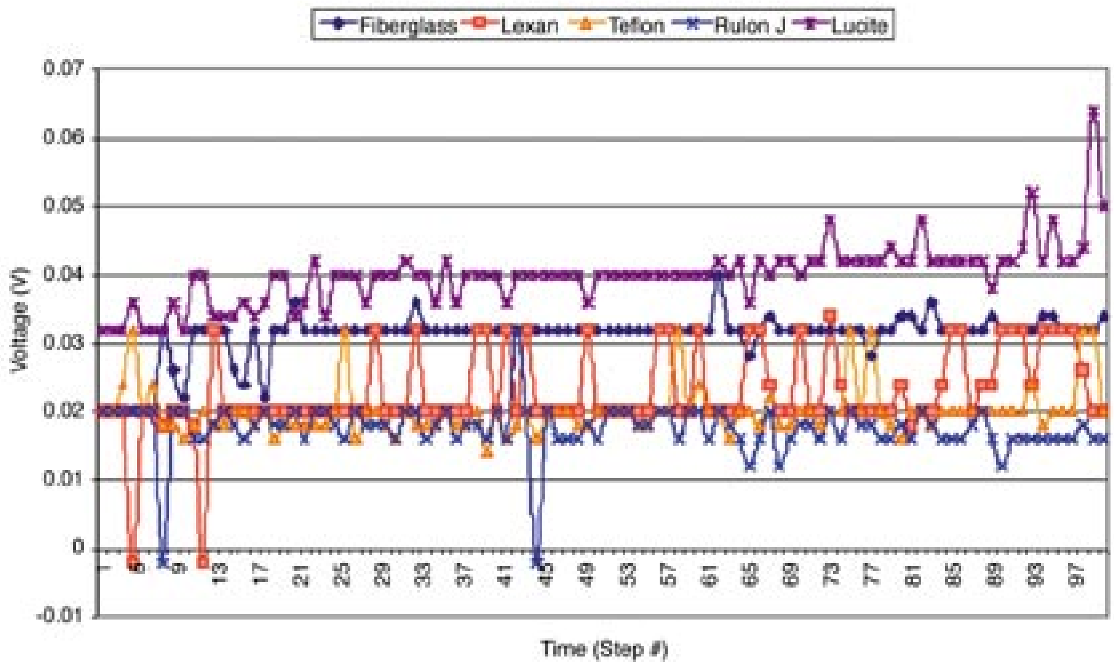

Figure 2. Rocking With Lunar Soil Simulant in Dry Air (760 Torr)

ratios for these materials are also being determined to understand the different electrostatic responses of individual dust particles, larger clumps of particulate matter, and sand-like particles. Several materials were also rubbed with the simulant to determine their electrostatic response. Typical voltages obtained are shown in figure 2.

The findings from this research effort will provide critical information and techniques for the successful operation of an extraterrestrial spaceport. The results could eliminate potential hazards relating to dust accumulation on equipment surfaces, astronaut suits, solar panels, habitat filters, thermal radiators, and other equipment that would degrade their performance or render them unusable. Commercial applications of the technologies developed could include the antistatic, paint, and grain industries.

Key accomplishments:

- Acquisition of an environmental chamber and a charge-to-mass system.
- Scanning electron microscope characterization of lunar simulant particles.
- Determination of the electrostatic response of lunar simulant particles exposed to insulating materials at low-humidity and low-pressure conditions.
- Determination of the maximum charge and charge relaxation times of lunar simulant dust particles.
- Determination of the charge-to-mass ratio of a distribution of lunar granular particles.

Key milestones:

- Experiment with actual lunar dust.
- Determine the charge generated on dust particles by photoemission due to ultraviolet absorption.
- Expose materials to charged and uncharged lunar dust under simulated lunar environmental conditions.

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Participating Organizations: Swales Aerospace (Dr. C. Buhler), Florida Institute of Technology (Dr. J. Mantovani), and YA-F2-T (E.E. Groop)

Mars Electrostatics Chamber

To fill the need for the increased research activity around NASA's exploration of Mars, the Electromagnetic Physics Testbed at KSC activated the Center's first operational Mars environmental simulation process – the Mars Electrostatics Chamber. Several important environmental characteristics of Mars were replicated in this chamber, including temperature, pressure, and atmospheric composition. Existing and newly acquired hardware was integrated with a centralized controller to bring about successful near-autonomous operation.

The Mars Electrostatics Chamber is 2 meters (m) in length, is 1.3 m in diameter, and has a volume of 1.5 cubic meters (m^3) (figure 1). The chamber has a 1.43- x 0.80-m Experiment Deck, a vacuum depressurization time of 20 minutes, and a controlled repressurization time of 10 minutes. It can be repressurized in an emergency in 10 minutes. Access ports are provided for component and peripheral device feed-through, existing pressure measurement, temperature signal lines, gas feed-throughs, and payload monitoring. The inside of the chamber is fitted with a cooling shroud.

Figure 1. Mars Electrostatics Chamber

The Mars Electrostatics Chamber has an automated control system with a graphical user interface. The automation system consists of three major systems: pressure control, atmospheric control, and temperature control. The atmospheric control system is used to monitor and maintain the gases contained within the chamber. The pressure control system is used to lower the pressure of the chamber to that of the Martian atmosphere. The temperature control system replicates temperatures within actual minimum and maximum values that would be experienced on Mars. A liquid/gaseous nitrogen supply and various heating techniques were used to obtain this temperature range. The optimal control of extremely cold nitrogen was fundamental to the stabilization of temperature within the chamber. After incessant testing and characterization, significant cooling implementation design changes, and controller instrumentation modifications, the cryogenic supply was successfully manipulated by a programmable controller system with appropriate programming. A cooling test is shown in figure 2.

A manual control panel was developed to add more flexibility to the chamber and as an alternative to the graphical user interface. This panel allows experimenters to select individual settings and perform manual tests while maintaining the safety

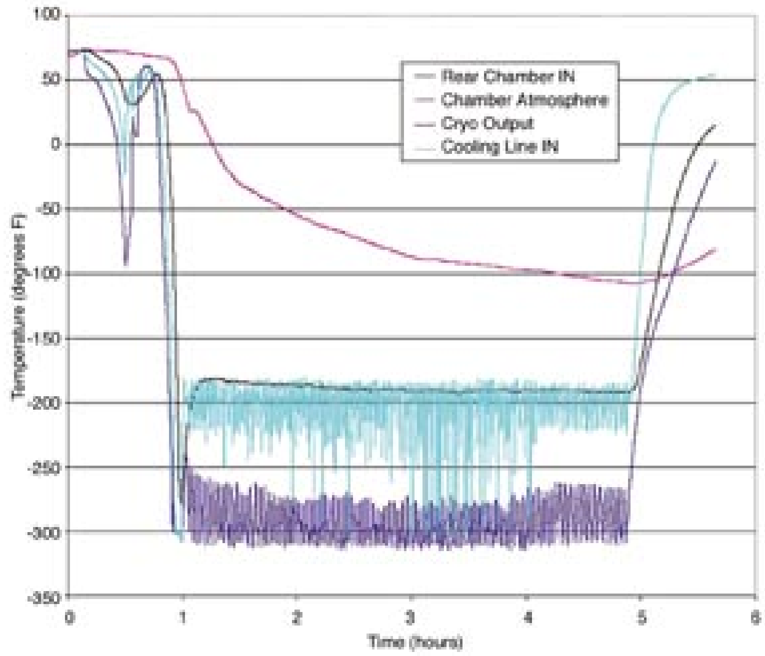

Figure 2. Cooling Test (07-21-00)

Mars Electrostatics Chamber Operating Characteristics

Operating Characteristics	Minimum	Typical	Maximum
Operating Pressure	0.2 torr	7 torr	760 torr
Operating Temperature	-120 °C	-100 °C	200 °C
Pneumatic Line Pressure		760 kPa	860 kPa
Chamber Pressure			130 kPa
Cooling Line Pressure			1000 kPa
Bakeout Temperature		150 °C	200 °C
Bakeout Pressure		0.5 torr	

associated with an automated system. The chamber operating characteristics are shown in the table.

Experiments using the Mars Electrostatics Chamber are in progress.

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Participating Organizations: VirCon Engineering (R.K. Buchanan and A.C. Barnett) and YA-F1-T (D.C. Lewis)

Martian Regolith Simulant Particle Charging

Airborne dust lifted into the Martian atmosphere by frequent dust devils can be transported by strong surface winds of daily occurrence during the Martian summer in the southern hemisphere. Dust and sand particles lifted into the wind stream can be carried for a distance, falling back to the surface where they can possibly kick up more particles, in a process known as saltation. The saltation action can create highly charged particles leading to adhesion and discharge. Since wind gusts in the Martian atmosphere can reach velocities of up to 100 meters per second, saltation and impact charging can be a significant issue in electrostatics on Mars.

To measure the amount of electrostatic charge generated on Martian regolith simulant particles, an apparatus was built that measured the degree of charging of the Johnson Space Center Mars-1 Martian Regolith simulant particles as they came into contact with different materials. The particles were dropped down a deflection board under a 5-millibar atmosphere to simulate the average pressure on the surface of Mars. The surfaces of the board were covered with copper, acetate, or glass sheets. It was speculated that the rolling, sliding, and bouncing of the particles would result in a net charge transfer, which could be measured with a Faraday cup and electrometer. The results were consistent with the triboelectric series and showed that the glass yielded a net positive charge to the simulant. The copper and acetate materials yielded a net negative charge to the simulant. A schematic representation of the experiment is shown in figure 1. Figure 2 shows the entire system in the vacuum chamber.

Key accomplishments:

- Design and construction of a saltation simulator for low-pressure testing.
- Acquisition of data for electrification of Martian simulant dust particles in contact with three different materials.

Key milestones:

- Improve the design of the system.
- Implement a mechanism to discharge the particles before they come into contact with the materials.
- Implement a corona-charging mechanism.
- Introduce an ultraviolet light source.

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Participating Organizations: Florida A&M University-Florida State University College of Engineering (Dr. F.B. Gross and S.B. Grek) and YA-F1-T (Dr. R.L. Lee)

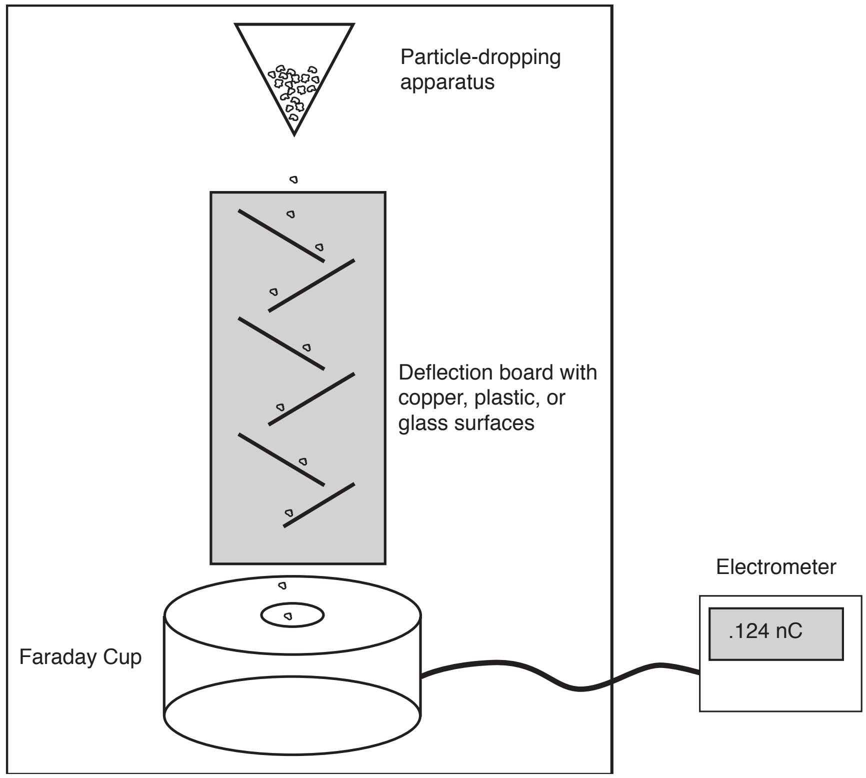

Figure 1. Schematic Representation of the Particle Charging Experiment

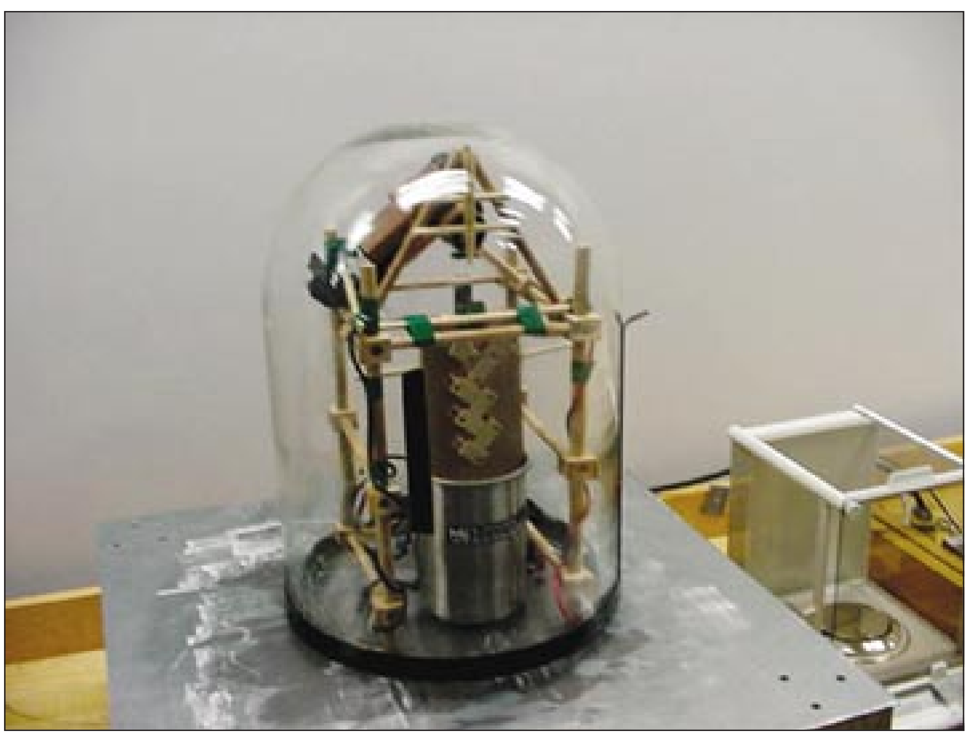

Figure 2. Experimental Setup for the Particle Charging Experiment

Mars Dust Impact Simulator

Dust in suspension in the Martian atmosphere can be transported by large occasional dust storms and by the more frequent dust devils. Moving dust particles can generate electrostatic charges as they come into contact with surfaces. Wind-driven particles can also collide with each other, transferring charge between them at each collision. Such charge separation generates electrostatic potentials that can damage equipment used on landing Mars missions. Charged dust particles can also adhere to solar cells and thermal radiator surfaces, degrading their performance.

To quantify the electrostatic characteristics of materials exposed to dust particles similar in composition to Martian dust, the Electromagnetic Physics Laboratory and Dynacs Inc. are designing a system to simulate the transportation of dust particles at speeds comparable to the highest speeds recorded on Mars during a dust storm. Comparison of absolute photometry of the Martian sky obtained by the Imager for Mars Pathfinder with multiple scattering models has shown the mean particle radius for airborne dust is 1.6 ±0.15 micrometers (μm). The amount of dust loading during a Martian dust devil has been estimated to be 700 times that of an ambient background. Maximum dust particle density has been calculated to be 2000 particles per cubic centimeter. The Viking mission recorded wind speeds of 30 meters per second (m/s).

The Mars Dust Impact Simulator will use a piezoelectric device driven by a signal generator to vibrate the particles, mechanically separating them and placing them under fluidized conditions. Once the particles are separated, the conductive impeller blades will thrust the particles onto several surfaces backed by electrometer sensors at velocities up to 30 m/s, simulating the Martian winds. The motion of the particles will be continuous, and the particles will impact the materials at angles nearly perpendicular to the surface. The simulator is small and is being designed as a self-contained low-temperature vacuum system. The temperatures and atmospheric pressures on the surface of Mars will be reproduced using a 100-percent carbon dioxide atmosphere.

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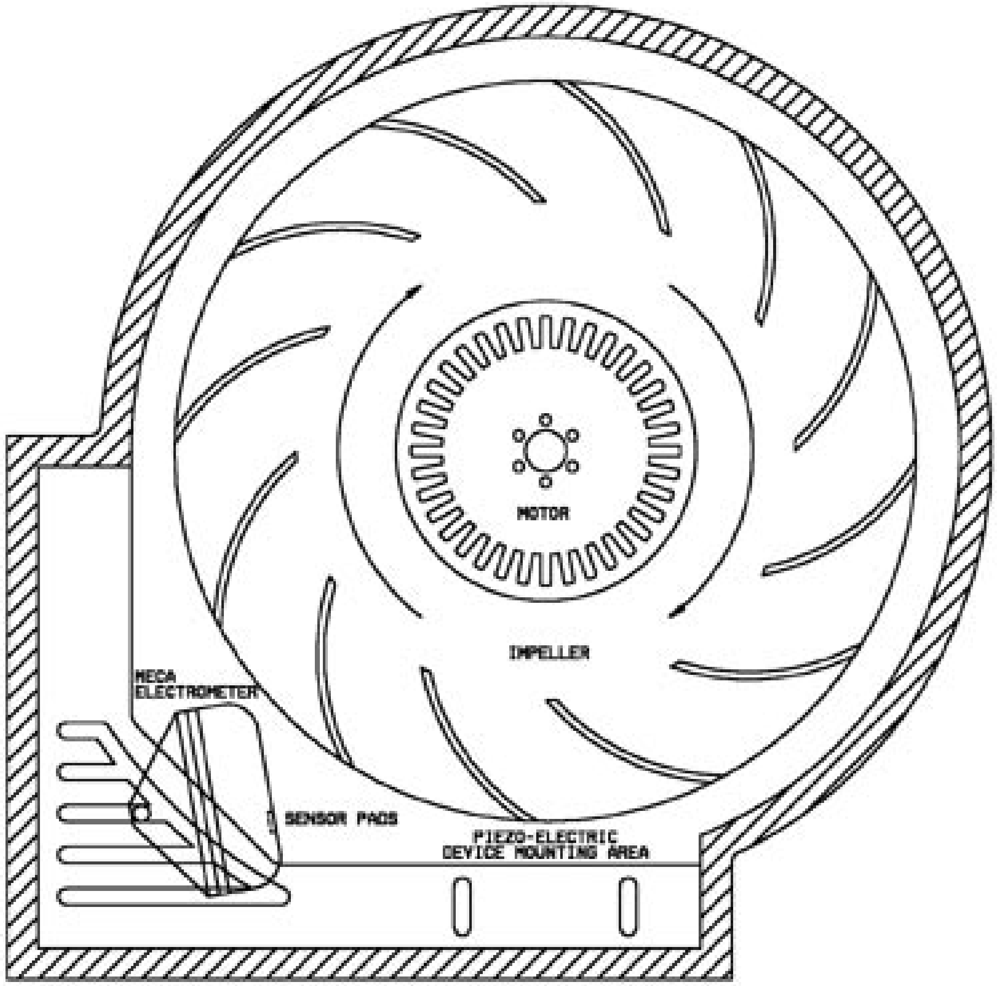
Participating Organizations: Dynacs Inc. (T.R. Hodge) and YA-F1-M1 (V.J. Cummings)



Conceptual Design of Mars Dust Impact Simulator

Composite Nondestructive Evaluation of Bonded Assemblies for the Space Shuttle and Space Station

Composite nondestructive evaluation (NDE) for the Space Shuttle will solve a recurring problem – ambiguous or incomplete NDE inspections – by providing the capability for accurate and precise detection of defects in bonded assemblies. This project uses the two emerging methods of shearography and thermography in conjunction with ultrasonics, all certified methods at KSC. While bonded composites on the orbiter are numerous and plentiful, operational needs have directed this project first toward two specific areas – flight crew equipment (FCE) lightweight components and external tank (ET) spray-on foam insulation (SOFI). Both Marshall Space Flight Center (MSFC) and Johnson Space Center (JSC) are closely involved with this work.

Shearography and thermography are optical systems and do not require contact with the surface. Compared with conventional methods, their inspection rates are very high. Shearography measures displacements that can correlate to structural properties or disbonds. Thermography measures temperature changes that can correlate to voids or disbonds. Comparing the results among several methods ensures the best inspection possible.

The basic approach for each application is to perform an assessment using commercial off-the-shelf (COTS) equipment to evaluate the sensitivity and accuracy of these methods. After an initial assessment, any needed improvements are developed by KSC, the manufacturer, or both, if feasible. Incorporating the method into an approved process requires operator training and certification and equipment certification.

The Flight Crew System is converting components from metal to composite (of graphite-epoxy skins and aluminum honeycomb core) as a weight-saving measure. Ensuring integrity of structure is imperative. Defining inspection intervals and content provides this surety. Since the components are designed for the life of the program, a reliability-centered maintenance approach will provide the remaining criteria to define intervals and content. During this year, recurring FCE inspections of pallets used in the crew module and midbody have shown the need for NDE. The inspections provide knowledge of the accuracy and sensitivity of shearography and thermography. In 2001, KSC and JSC will define the inspection requirements. Then, NASA, Boeing, and United Space Alliance (USA) engineering will determine how to incorporate these requirements into an operational process.

The ET SOFI has a history of debonding, sometimes striking the orbiter tile and causing damage. For this reason, shearography provides an opportunity to evaluate known areas of concern, to perform acceptance testing of new SOFI materials at MSFC, and to be an alternative to the existing methods of SOFI bond verification. MSFC and KSC developed a test plan to determine the accuracy and sensitivity of shearography for detecting SOFI disbonds. An initial assessment showed that a shearography upgrade was necessary. The upgrade is underway, and testing is set to resume early in 2001. (See the figures for a comparison of image quality.) Following completion of testing, implementation will begin as early as 2001.

Follow-on applications include additional FCE components, orbiter structure, certain orbiter thermal protection systems (TPS), orbiter tires, and leak detection. Operational priorities will determine the priority of these applications.

This project will develop operator certification and training with participation from USA and

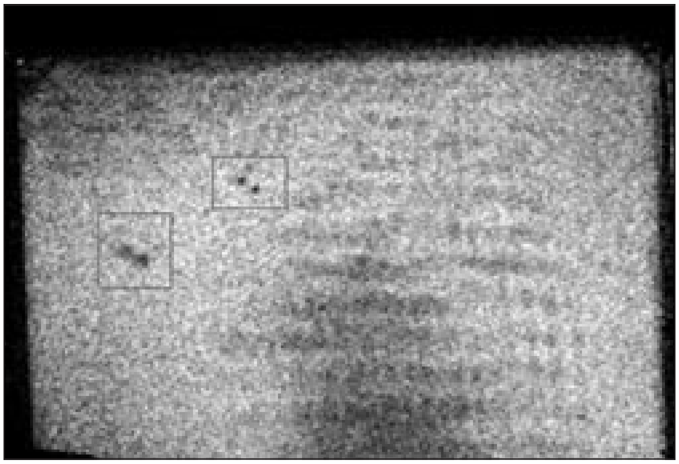


Figure 1. External Tank SOFI Test Panel: Shearography Images of 0.25- and 1.5-Inch Defects

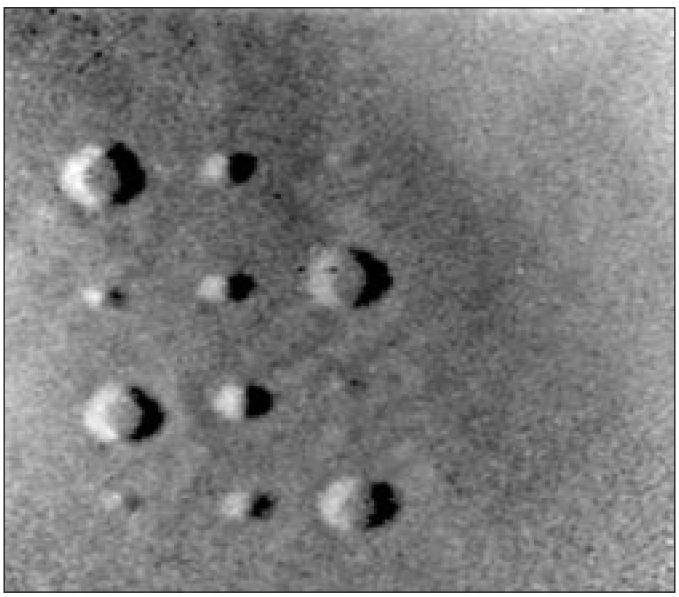


Figure 2. Graphite-Epoxy Test Panel With Improved Shearography System

Boeing. This project will coordinate with the Code Q NDE committee, design centers, and USA to provide the expertise necessary to incorporate this capability into Shuttle operations. Further, the reports and techniques developed will form the basis of the NDE Standard Repair Manual and Web-based training.

NDE, like any launch process, is an expertise that makes KSC more marketable as a center of excellence. As is true with most launch processes, experience figures prominently towards expertise. KSC included NDE as a core capability for the Spaceport. Cape Canaveral Air Force Station and future launch vehicles and payloads are potential customers, as is the aeronautics (aircraft) industry. Delta IV SOFI is an obvious application.

Key accomplishments:

- Initial assessment of FCE lightweight pallets, middeck accommodations rack, and tool storage assembly.
- Follow-on inspections of FCE pallets.
- ET SOFI for KSC and MSFC uses.
- Shearography upgrade to provide additional sensitivity for SOFI.
- Initial implementation plan development.

Key milestones:

- 2001: Complete shearography upgrades. Complete the FCE pallet testing to determine inspection intervals and the content. Complete the ET SOFI test plan to determine applications. Initiate FCE and ET SOFI implementation plans. Determine follow-on application prioritization.
- 2002: Develop techniques for most orbiter composite structures.

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Launch Systems Testbed (LST)

The Launch Systems Testbed is a combination of capabilities that includes specialized personnel with structural dynamics and launch environment analysis experience; a launch environment database; launch environment prediction and structural analysis methodologies; a small-scale launch environment test capability; and an international consortium of partners in Government, the space launch industry, academia, and commercial product vendors with a common goal of enhancing the research and development of vibroacoustics and structural analysis in launch environments. All these are incorporated under one umbrella to meet the specific requirements of customers worldwide, while promoting excellence in the field of acoustics, vibration, and structural design and analysis associated with the launch of space vehicles.

KSC and the adjacent Cape Canaveral Air Force Station are prime sites for performing launch system research because of their history. The LST is the evolution of vibroacoustic research and development work performed at KSC over the last 15 years. Because of the unique nature of a launch environment, there is incomplete knowledge within the aerospace industry and the Government on the prediction of and structural response to launch environments. The problem is acute for new launch systems that have never been launched and require the design of reusable and survivable launch facilities with launch environment mitigating features.

Initial plans call for designing and constructing a test capability that can be configured to scale launch environments of future vehicles. The scaled launch environments will be used to predict the full-scale launch environment. In addition, the ability to perform scaled testing of launch pad structures, equipment, and exhaust ducts will be included. This testing will seek to develop novel launch pad designs and verify designs under study. LST projects focus on the following technical areas: vibration response, acoustic suppression systems, exhaust plume modeling using computational fluid dynamic (CFD) codes, flame trench configuration optimization, scaling methodologies, assessment of composite structures, fatigue life prediction, hydrogen entrapment, and the effects of liftoff on ground structures and support equipment.

While developing potential customers within the space launch industry, the LST will provide a one-stop shop for the assessment of advanced structures and structural materials, including composite, inflatable, and other nontraditional structures for nonterrestrial launch systems. KSC personnel, in concert with other Government organizations, U.S. and international academia, and industry, are developing the LST test infrastructure to analyze, design, and test innovative launch structures, equipment, and environment attenuation systems for future NASA space initiatives. The LST will feature a one-of-a-kind, scaled, moving, combusting, and noncombusting supersonic jet plume test laboratory.

Current work at the LST located in the KSC Industrial Area includes:

- Establishment of a scaled launch environment test facility to characterize acoustics, vibration, and the exhaust plume using KSC-developed codes

- Design and construction of a trajectory simulation mechanism (TSM) to simulate launch trajectory effects

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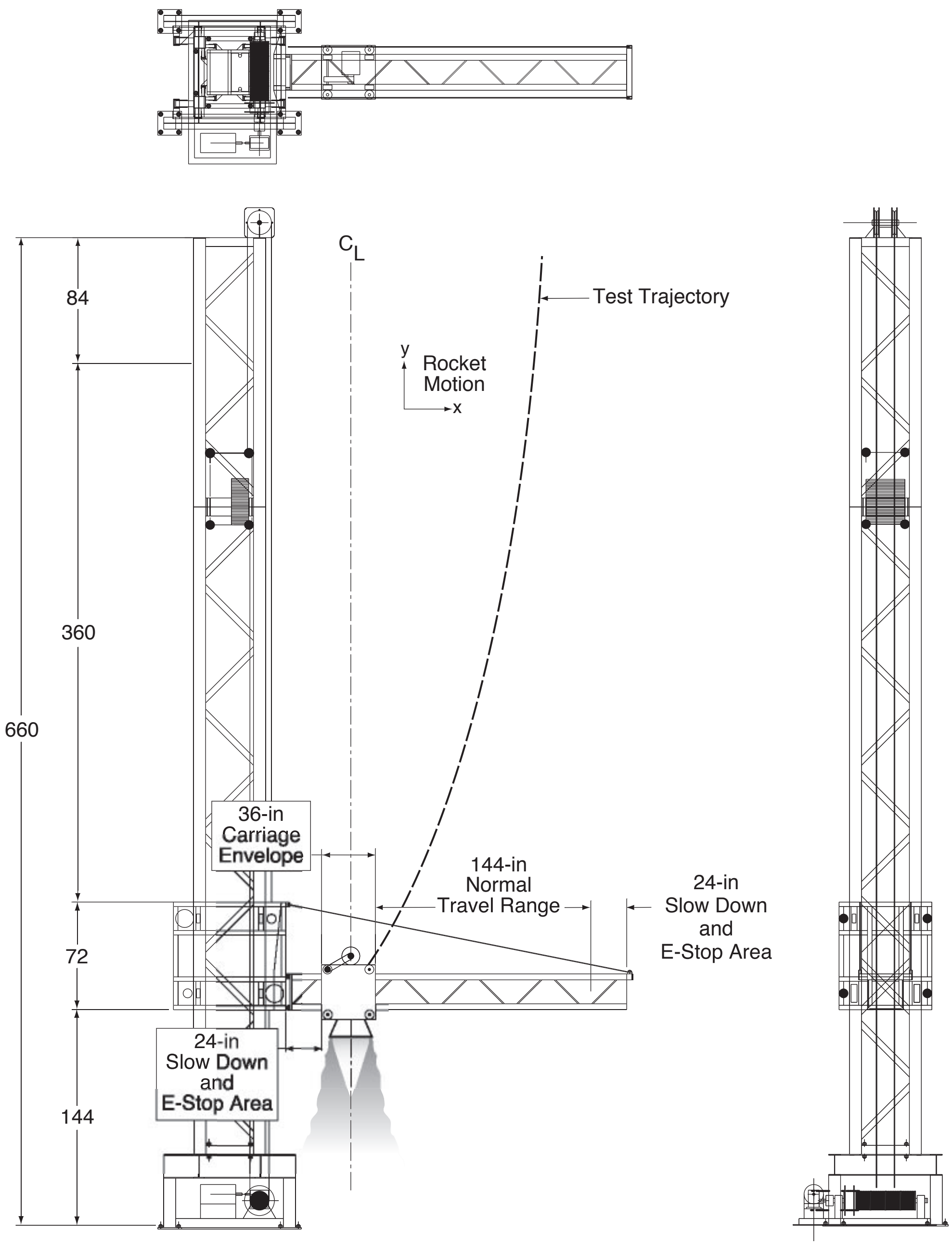
Participating Organization: Dynacs Inc. (Dr. R.N. Margasahayam)



Trajectory Simulation Mechanism (TSM)

U.S. Army Corrosion-Retardant Additive Testing

The objective of this project is to test and analyze chloride rinse agents (CRA's) for use on U.S. Army aircraft, missiles, and ground vehicle systems and components. NASA and Dynacs Inc. are testing the effectiveness of CRA's to prevent or reduce corrosion of metals exposed to salt spray. Nine different metals specified by the U.S. Army are presently experiencing a harsh, outdoor marine environment at the NASA/KSC Beach Corrosion Test Site. Solutions of CRA's are sprayed onto metal coupons each week. The coupons will be observed for corrosion activity for 2 years using several analytical measurements in addition to visual observation. Research is also being conducted to compare a new electrochemical impedance spectroscopy sensor that operates in atmospheric conditions. The data collected with this new sensor will be compared to visual observations to evaluate this method as a tool for predicting corrosion initiation.

The present efforts are to:

- Determine any adverse effects of test products on test materials and surfaces. NASA will define the appropriate usage measures to reduce or eliminate identified adverse effects.

- Define the optimum methodology for applying test products on U.S. Army systems.

- Conduct comparison testing of products and report the findings and recommendations. As a minimum, four CRA's will be compared to seawater, demineralized water, and no rinse as controls. Rust quantification will include visual observation, weight loss, and pit analysis.

- Conduct test product off-gas analysis of test coupons, components, and materials.

Key accomplishment:

- Deployment of test stands and coupons.

Key milestone:

- Progress report on weight loss measurements of coupons.

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Participating Organization: Dynacs Inc. (J.J. Curran, Dr. R.G. Barile, and R. Springer)

Metal Coupons for Chloride Rinse Agent Testing

Test Matrix

Topic	Test Description
Metals	Aluminum 2024-T3 with 8625 coating Aluminum 2024-T3 with 5539 coating Aluminum 7075-T6 Magnesium 4377 with 3171 coating Steel 4340 PH 13-8 Mo high-strength steel (AISI type 13800) AM-355 CRT high-strength steel C-250 maraging high-strength steel, AISI grade 18 Ni (250) 6Al-4V (Ti-6Al-4V), UNS R65400
CRA's and Controls at Weekly Rinses	CRA — Dilution Ratio With Demineralized H_2O 1 — 16:1 2 — 50:1 3 — 16:1 4 — 200:1 Controls: 1. Seawater 2. Demineralized water 3. No rinse
Test Material Configuration per Metal	For each metal: 6 coupons x (4 rinses + 2 rinse controls) + 6 x 1 no rinse control = 42 coupons per metal
Exposure Periods	3 coupons: 1 year; 3 coupons: 2 years
Evaluation Methods	Visual (weekly); corrosion sensor (monthly); Weight loss (1 and 2 years); metallurgical and off-gas (1 and 2 years or as soon as failure occurs)

Corrosion-Resistant Tubing for Space Shuttle Launch Sites

The existing 304 stainless-steel tubing at the Launch Complex 39 launch pads is susceptible to pitting corrosion that can cause cracking and rupture of the high-pressure gas and fluid systems. The failures can be life threatening to launch pad personnel in the immediate vicinity. Outages in the systems where the failure occurs can affect the safety of Shuttle launches. These failures have been documented in reports such as MSD Report 95-1M0040.

Improved corrosion-resistant tubing systems will greatly enhance both personnel and Shuttle safety concerns. These new-generation materials will require less maintenance over their lifetime and significantly reduce costs associated with these systems.

Exposure of test articles at the KSC Beach Corrosion Test Site with concurrent applications of acidic slurries to simulate solid rocket booster deposits is underway. The performance of the various tubing alloys for corrosion resistance is being evaluated in the Corrosion Technology Testbed Facilities.

Benefits of this project include:

- Corrosion-resistant tubing in launch pad applications that would greatly reduce the probability of future pitting corrosion failures.

- Improved safety and lower maintenance costs that would result from using the more corrosion-resistant alloys.

- Increased reliability of all launch pad high-pressure gas and fluid systems.

Key accomplishments:

- Identification of domestic fabricators/suppliers of seamless and seamed annealed tubing of corrosion-resistant alloys.
- Procurement of samples of the tubing for evaluation.
- Fabrication of tubing test articles.

Key milestones:

- Determination of performance and cost benefits to recommend a new material for Launch Complex 39 applications.
- Sponsorship of an informational workshop by the Nickel Development Institute.

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Participating Organization: Dynacs Inc. (J.J. Curran, T.R. Hodge, and J. Staub)

Corrosion-Resistant Tubing Test Articles

Evaluation of Corrosive Effects of De-Icing Chemicals on Steel Reinforcement in Concrete

The NASA Corrosion Technology Testbed of the Laboratories and Testbeds Division and Dynacs Inc. are evaluating the effect of a replacement for de-icing salts on the embedded steel reinforcement in concrete. Presently, sodium chloride (NaCl) and potassium chloride (KCl) salts are used to aid in the removal of ice from state highways. These salts are not materially or environmentally friendly and cause corrosion to bridges, roads, and associated structures. In addition, these salts affect the growth of roadside trees and vegetation. The two replacement formulations under study are a byproduct of feed used in the cattle industry. The byproduct, ICE-BAN, is basically a corn alcohol with other chemicals added.

The current effort utilizes a laboratory test method based on the American Society for Testing and Materials standard ASTM G109, Determining the Effects of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments. These test guidelines are used to evaluate the effect of de-icing chemical formulations on reinforcing steel in concrete. The ASTM G109 method is a relatively new method that is very adaptable for other evaluations, such as new reinforcing materials, new admixtures, posttreatment corrosion-inhibiting chemicals, new concrete design, and new concrete material testing. The effect of each formulation is determined by electrochemical measurements and autopsy of the reinforced concrete test blocks at the end of the test design cycle. The electrochemical measurements include reference half-cell potentials and corrosion data. To date, no adverse effects due to the treatment have been noted.

Key accomplishment:

- Proved that no adverse effects occur when ICE-BAN is used on concrete surfaces.

Key milestone:

- 2001: Autopsy concrete and photograph embedded reinforcing steel for potential long-term effects of ICE-BAN.

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Participating Organizations: Dynacs Inc. (J.J. Curran and D.N. Bardel) and HITEC (A. Murphy)

Concrete Specimens Used for De-Icing Testing

Development of Liquid Applied Coatings for Protection of Steel in Concrete

Corrosion of reinforcing steel in concrete is an insidious problem facing KSC, other Government agencies, and the general public. These problems include KSC structures, highway bridge infrastructures, and building structures such as condominium balconies. Because of these problems, the development of a Galvanic Liquid Applied Coating System (GLACS) would be a breakthrough technology having great commercial value.

Successful development and continued optimization of this breakthrough system would produce great interest in NASA/KSC for corrosion engineering technology and problem solutions. Commercial patents on this technology would enhance KSC's ability to attract industry partners for similar corrosion control applications. The present effort is directed at several goals:

- Phase I concentrates on formulation of coatings with easy application characteristics, predictable galvanic activity, long-term protection, and minimum environmental impact. These new coating traits, along with the electrical connection system, will successfully protect the embedded reinforcing steel through the sacrificial cathodic protection action of the coating.

- Phase II improves on a Phase I formulation that includes optimizing metallic loading and incorporates a humectant for continuous activation of the GLACS.

- Phase III includes development of optimum electrical connections that leads to better sacrificial electron flow.

Laboratory testing has shown this technology to be feasible. Presently, tests are being conducted at the NASA KSC Beach Corrosion Test Site with positive preliminary results. In addition, the generated data is being collected and remotely accessed from off-site locations.

This new liquid applied materials system will protect existing KSC and NASA structures and have significant commercial applications for transportation infrastructure, marine infrastructure, civil engineering, and construction industries.

Key accomplishments:

- Proved the feasibility of using liquid applied coatings for protection of embedded reinforcing steel in concrete.
- Determined the optimum mix ratio for specific liquid applied coatings.

Structural Concrete Specimens at Beach Corrosion Test Site

Key milestone:

- 2001: Move the liquid applied coatings testing from small-size samples (11 x 6 x 4.5 inches) to larger structures (4 feet x 4 feet x 7 inches). The new structure concrete design mix will include chlorides to simulate a contaminated reinforced concrete structure.

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Participating Organization: Dynacs Inc. (J.J. Curran and Dr. R.G. Barile)

Process and Human Factors Engineering

Process and Human Factors Engineering (P&HFE) is a technical discipline devoted to the science of process design, management, and improvement and to the optimization of operational phases of complex systems by focusing on the interfaces among hardware and software systems, processes, and humans in specific work environments. The goals of this discipline are to enhance safety, efficiency, and effectiveness and to improve quality. P&HFE is becoming an area of increased importance due to the long-term operational phases of current and potential future human space flight programs. The research and technology affiliated with P&HFE include:

- Human Factors Engineering
- Process and Operations Modeling, Simulation, and Analysis
- Life Cycle and Risk System Assessment
- Work Methods and Measurement
- Scheduling and Capacity Analysis

For more information regarding Process and Human Factors Engineering, please contact Deborah Carstens, (321) 867-8760, *Deborah.Carstens-1@ksc.nasa.gov,* or Tim Barth, (321) 867-6230, *Timothy.Barth-1@ksc.nasa.gov.*

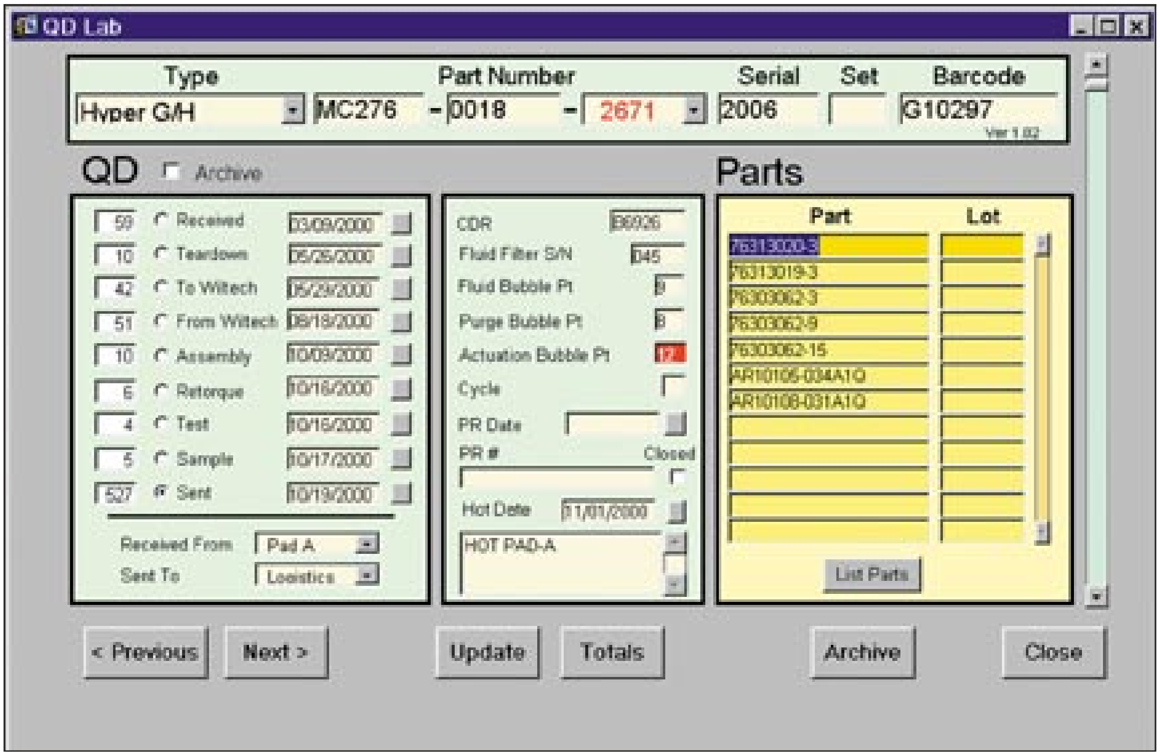
Disconnect Automated Resource Tracking (DART) Software

The Quick Disconnect (QD) Laboratory processes quick disconnect hardware used to transfer pressurants and hypergolic propellants into the Space Shuttle's Orbital Maneuvering Subsystem (OMS) pods and the Forward Reaction Control System (FRCS). Hypergolics are extremely toxic and corrosive chemicals. As a result, QD's must be regularly rebuilt and inspected to maintain proper filtration and avoid hypergolic leaks or spills. The QD Laboratory services almost 2,000 items annually that require different levels of service.

Prior to the installation of the DART software, the QD Laboratory had no effective tracking method. If management wanted to know how many QD's were at Wiltech for cleaning, a technician had to physically count the QD's on the shelves. In addition, there was no automated tracking of QD's by part number/serial number or problem reporting (PR) history. There was no real-time status information, no location information, and no configuration information. As a result, there was no consistent internal tracking to assist scheduling and job planning.

Using Oracle Developer 6.0 and IBM ViaVoice 7.0, the design team solved the QD Laboratory internal tracking problems by enhancing internal controls in several different ways. Using a comprehensive input screen designed in Oracle Forms, the program tracks each individual QD refurbishment by status and date. Forty automated reports provide internal processing information by status, type, PR history, and priority. Where appropriate, the reports accept user-defined parameters. This information permits the effective assignment of items to Parts and Materials Requests (PMR's) and

Disassembled QD Showing the Wide Variety of Components



Main QD Input Screen Tracks Both Current and Historical Data

the establishment of priorities. This greatly enhances the efficiency of the QD Laboratory and assists in scheduling. For the first time, the DART software tracks the total processing flow within the laboratory.

The QD Laboratory now has real-time status, location, and configuration information. This not only saves time, it helps ensure these components are ready to support vehicle processing when needed. The database also lists internal QD soft goods to allow tracking these items by lot and the number of cycles each QD and its related items have experienced. Artificial intelligence (AI) programming techniques color-code part numbers on the input screen to match the color codes of Fuel, Oxidizer, and Clean Gas QD's. Additional AI features provide enhanced error checking when a new QD is entered into the program.

As an added feature, the DART software developers designed the program to work effectively with voice recognition software. The program was installed with IBM ViaVoice 7.0, which users found to be both accurate and interesting to use. This adds convenience and flexibility to data input and update efforts. Management conservatively estimates a savings of 500 hours per year.

Key accomplishments:

- 2000: Software design and report design complete. Initial coding complete.

Key milestones:

- 2000: Coding complete. System fully implemented.

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Participating Organization: United Space Alliance (R.M. Edwards and S.M. Schneider)

Cartridge Automated Resource Tracking (CART) Program

The Lithium Hydroxide (LIOH) Laboratory refurbishes the Environmental Control Life Support System (ECLSS) air purification cartridges used by the Space Shuttle flight crew during flight. These cartridges are a mission-critical flight element. Every processing step and all chemical consumables must be carefully tracked and reported to NASA, Johnson Space Center (JSC), and United Space Alliance management.

Previously, the LIOH Laboratory used a stand-alone database coded in Microsoft FoxPro. The tracking program became operational in 1995 and served the LIOH Laboratory well. However, the extraordinary technical advances in microcomputers/communications over the last 5 years made the FoxPro software obsolete.

The FoxPro program was not on a server, so technicians had to retrieve data from a disk when working on different computers. The original program used standard VGA resolution, which severely limited the available screen “real estate.” This limitation required multiple input pages to contain the complete set of data inputs. Users had to constantly switch back and forth between these pages to view all the required data.

STS-40 Pilot Sidney Gutierrez Changes the LIOH Canisters on the Middeck of Columbia

In addition, there was no way for the JSC counterparts (or anyone outside the LIOH Laboratory) to directly view cartridge processing data. When an outside agency requested cartridge processing information, technicians were required to run a report on the local computer, print it, and then fax the report.

To solve this problem, the team recoded the CART system in the latest version of Oracle Forms, Reports and Graphics: Oracle Developer 6.0. Five years of lessons learned were applied. As a result, the LIOH Laboratory eliminated redundancies, simplified report formats, and restructured table dependencies. The team maintained (and in many cases enhanced) the program’s original functionality and simultaneously simplified data input and screen displays. All critical data is now displayed on a single SVGA screen and is viewable at a single glance.

The processing data is kept on a central Oracle server, thus eliminating the previous disk-swapping required to transfer data between different computers. The server also provides automatic backup and storage services. This not only enhances data safety, it eliminates the need for LIOH Laboratory personnel to constantly produce multiple copies of backup floppy disks.

In addition, the team designed a special Oracle form and published it on the World Wide Web. This gives outside agencies the ability to select and view more than 20 different reports (many with user-defined parameters and some with embedded graphics) anywhere in the world. The new Oracle tracking and reporting program is truly state of the art. A sampling of the reports available includes Cartridge Production and Manifests for Flight Crew, Space Hab, and the Space Station Freedom. Florida Clean Air/Water Reports, which determine the amount of trace chemicals released into the environment, are now available real-time to Environmental Safety and Health.

The LIOH Laboratory developed modern software capabilities and published them on the Web. This provides enhanced real-time reporting capability and simultaneously reduces the significant work hours expended to make them available. Using the CART software, the LIOH Laboratory was able to maintain both production and safety when the processing work force was significantly reduced.

December 14. 2000 12:16 PM

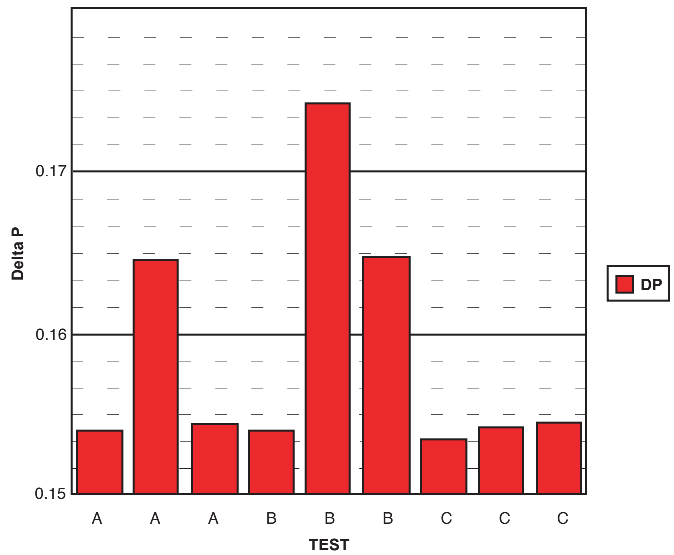
Delta P for CO Absorber

USA United Space Alliance

CO Absorber

Serialno 00001 Pack Date 10/23/1997

Test	Test Date	CFM	DP	UCL	LCL	G	Fm	A	B	C	D	E	F	Weight
A	01/01/2000	20.4	.1539	.7299	.3785	30.1	55	20	25	72	.62	73	.2	2835 Original Weight
A	06/08/2000	20.4	.1646	.7299	.3785	30.08	55	20	25	75	.6	74	.2	2840 1st Flight
A	11/10/2000	20.4	.1544	.7326	.3795	29.9	55	20	25	71	.4	71	.2	2845 2st Flight
B	01/01/2000	25.6	.1539	.8778	.4328	30.1	69	25	25	67	.75	73	.2	
B	06/08/2000	25.4	.1742	.8745	.4316	30.08	69	25	25	71	.7	72	.2	
B	11/10/2000	25.6	.1647	.8787	.4331	29.9	69	25	25	70	.45	71	.2	
C	01/01/2000	30.7	.1535	1.018	.482	30.1	84	30	25	64	.9	72	.2	
C	06/08/2000	30.7	.1542	1.018	.482	30.08	83	30	25	69	.8	74	.2	
C	11/10/2000	30.8	.1544	1.020	.4826	29.9	83	30	25	68	.45	71	.2	



The CART Software Automatically Generates a Wide Variety of Reports

Key accomplishments:

- 1999: Software design and report design complete. Initial coding complete.

Key milestones:

- 2000: Coding complete. System fully implemented.

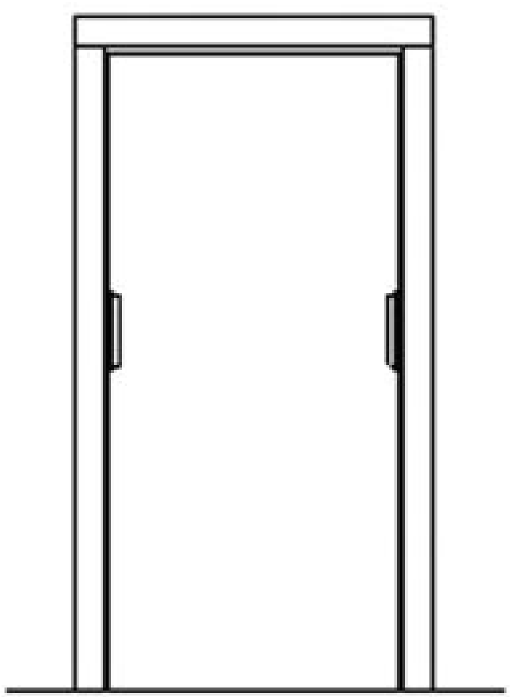
Contact: P.J. Bookman (Pamela.Bookman-1@ksc.nasa.gov), YA-C1, (321) 867-6210

Participating Organization: United Space Alliance (C.L. Ehrenfeld and S.M. Schneider)

Wireless Technology for Logistics Applications

The purpose of this project is to study the feasibility of replacing bar code technology with a next-generation system that does not require human interaction. A radio frequency identification (RFID) system is being developed for this application. A typical RFID system consists of three basic parts: the database (if a central database is used), the reader, and the transponder (Tag). Communication is required between the transponder and the reader and between the reader and a centralized database. Wireless technology is used for the transponder-to-reader communication. The reader-to-database communication uses a serial interface and/or network technology.

The RFID system technology is currently fragmented. There is no standardization at any level. At least eight carrier frequency bands are in use around the world, ranging from 100 kilohertz to 2.45 gigahertz. Many of the product lines are sold as complete systems and do not interface with others except at the database software level. There are competing hardware and software products that can be used to create a system at virtually any level of commercial integration.

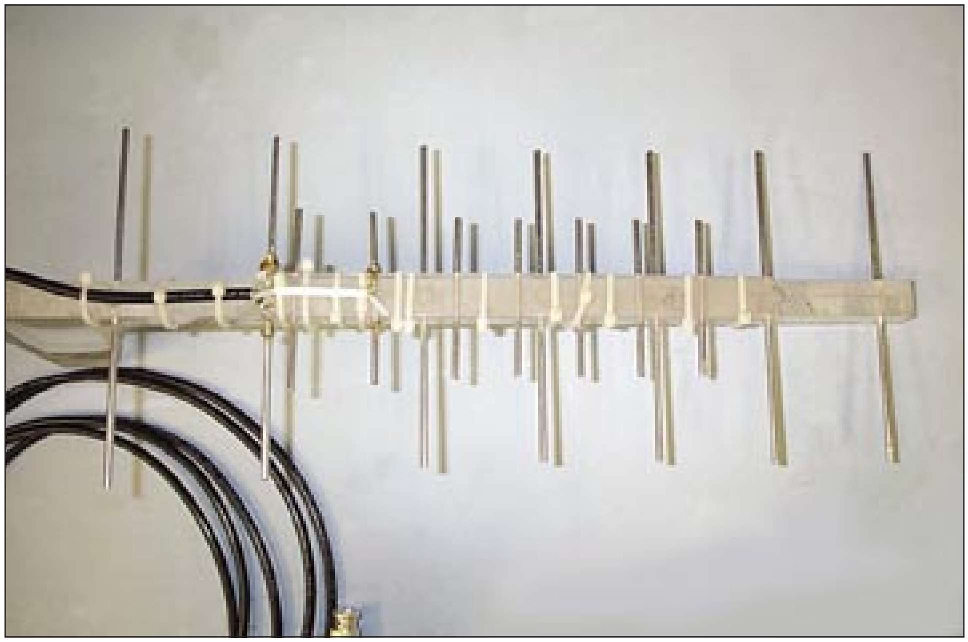


Door Portal With Two Antennas

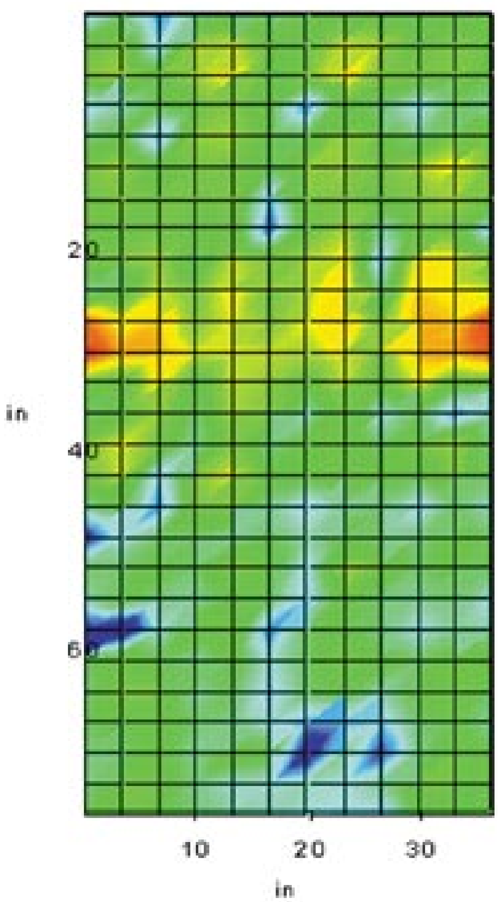
There are two main categories of Tags – active and passive. Active Tags have a battery power source, which limits their maximum life expectancy to about 6 years. The battery makes the Tag substantially larger and more expensive but gives the system a much longer read range. Passive Tags get their power from the reader's transmitted carrier frequency. The Tag captures the energy transmitted from the reader and uses it to transmit back to the reader. The power-level limitations of the reader's transmission limit the range. Compared to active Tags, passive Tags are inexpensive and small and have no defined life expectancy limits.

The method being developed for this project will track tagged property as it passes through portals at doorways. The portal will consist of a Tag reader with multiple antennas and several photocells and will detect the assets and the direction of movement. The portal reader will then transmit this information to a central database that will show the item moved from one location to another. A Tag reader could also be developed to specifically satisfy KSC requirements. The most promising frequency bands for the operation of the system are being evaluated by testing commercial off-the-shelf (COTS) products. Tag collision resolution algorithms are also being analyzed.

A hand-held directional reader/locator, with an extended range to help locate lost tools, was developed and is being tested. This Tag locator will need to sense the presence of a Tag and possibly estimate the distance from the locator to the Tag.



Prototype Yagi Directional Antenna



Portal Response Plot

Key accomplishments:

- A portal with two antennas operating at 915 megahertz was built and is undergoing testing and characterization.
- A highly directional reader was prototyped and successfully tested.
- Software for the real-time update of Tag information was developed.

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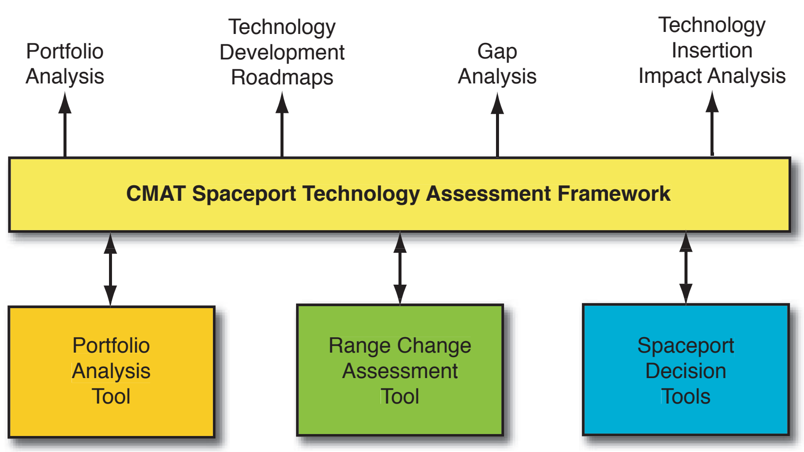
Participating Organization: Dynacs Inc. (J.D. Taylor, Dr. P.J. Medelius, J.J. Henderson, and Dr. C.T. Mata)

Change Management and Analysis Tool (CMAT)

A key characteristic that will distinguish successful enterprises of the new millennium is the ability to respond quickly, proactively, and aggressively to unpredictable change. Robust methods and tools to facilitate change management are, therefore, essential for the modern enterprise. This project targets the technology gaps and challenges associated with strategic change management: (1) lack of scientific methods for strategic change management; (2) lack of information-integrated software tools to support the change management process; and (3) lack of knowledge management mechanisms that capture, store, and leverage corporate knowledge for strategic planning and control.

The project proposes to design, develop, and deploy a Change Management and Analysis Tool (CMAT), an integrated software system that facilitates strategic change management. The project will define CMAT application requirements at KSC, develop and validate a robust CMAT application, and commercialize CMAT technology. Key project innovations include a novel adaptation and application of portfolio theory for strategic decision support, a scalable simulation-based approach for change impact assessment, and a structured knowledge-based method for strategic planning and change management. CMAT is expected to significantly improve NASA's change management capability in the near term. To date, the main activities of the project include (1) defining focus application areas at KSC, (2) defining requirements for the CMAT Portfolio Analysis Tool, (3) defining the structure of a scalable simulation framework for change impact assessment, and (4) gathering requirements and data for a scalable range simulation model.



CMAT Architecture

Key accomplishments:

- 1999: Successful completion of the Phase I SBIR project. Development of the CMAT prototype.
- 2000: Selection for Phase II SBIR research and development. Definition of KSC focus areas. Development of a preliminary simulation-based change impact assessment framework. Development of project portfolio analysis visualization mechanisms.

Key milestones:

- 2001: Completion of the scalable range simulation model. Development of a prototype portfolio analysis tool. Completion of the change management method. Refinement of the simulation-based change impact assessment framework.

- 2002: Completion of the Phase II project. Completion of CMAT software tools. Development of a technology transfer and commercialization approach.

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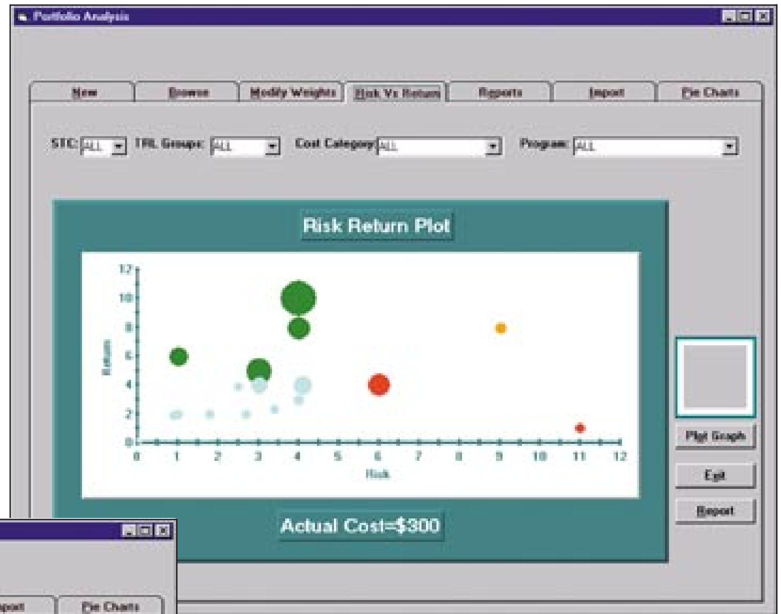
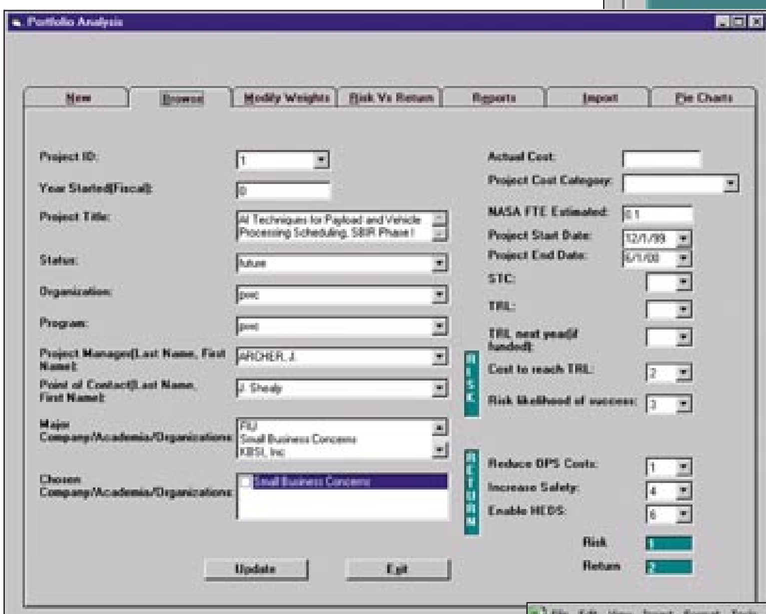
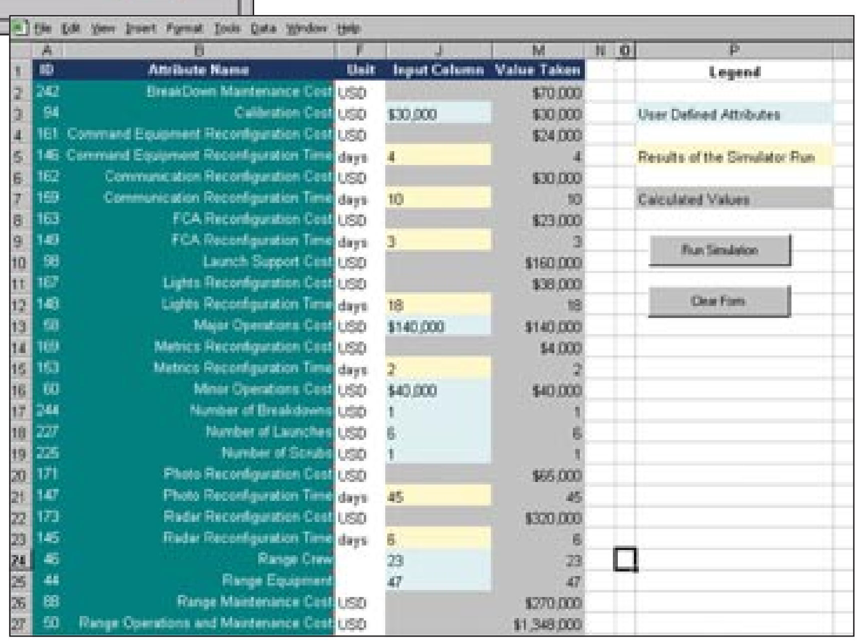
Participating Organization: Knowledge Based Systems, Inc. (Dr. P.C. Benjamin)







Spaceport Technology Center and Work Instruction Delivery Initiative

NASA's new vision for KSC requires that it create a Spaceport Technology Center (STC) to support the development and widespread use of new and existing technologies and to enable safe, reliable, and low-cost access to space. There are six primary technology investment areas under the STC concept:

- Fluid System Technologies
- Spaceport Structures and Materials
- Process and Human Factors Engineering (P&HFE)
- Range Technologies
- Command, Control, and Monitoring Technologies
- Biological Sciences

P&HFE provides a systems approach to design, management, and implementation of processes. P&HFE focuses on the interface among workers, hardware, software, and the work environment. Thus, activities across KSC can benefit from the use of P&HFE technologies and principles. Furthermore, spaceport processes have many unique aspects that require development of innovative P&HFE modeling and analysis technologies. Hence, it is necessary that KSC develop capabilities to test innovative ideas and concepts. Such capabilities should lead to greater interaction and partnerships between KSC and academia, research centers, and industry.

This effort seeks to investigate how to establish a Process Engineering Technology Center (PETC) that will disseminate existing technologies used at KSC and, at the same time, be a testbed for the development of new P&HFE technologies. The PETC initiative is envisioned as a multiphase effort. The initial phase will yield a blueprint for full-scale implementation and develop a testbed. The PETC will support the KSC roadmap by providing not only a focal point for the Center's P&HFE technology development activities but also a showcase for P&HFE technology success stories and current activities. Specifically, the primary objectives of this project are to:

- Provide a focal area for visiting and in-house P&HFE technology developers
- Develop a roadmap for the establishment of P&HFE technology testbeds
- Enhance reliance and teamwork within KSC's P&HFE community
- Develop a showcase supporting P&HFE education and awareness, new business development, and partnerships

The initial testbed is focused on Work Instruction Delivery (WID). It seeks the introduction of wearable computers in Shuttle processing operations. For the WID Testbed, various commercial off-the-shelf (COTS) delivery systems are being researched and tested, including head-mounted devices, voice-activated devices, and wearable computers in a wireless environment. The experiments will lead to the following elements:

- An understanding of what types of devices are feasible to enable electronic delivery of the work instructions, including hardware and software that can interact with KSC's information systems as well as be comfortable and nonhazardous to the technicians. Examples of these tools are head-mounted devices, voice-activated devices, and personal monitors.

- The design of a training program so the chosen technologies can be used effectively by technicians.

Key accomplishments (2000):

- PETC Showcasing: Conceptualization of the PETC message in the form of posters and pamphlets for success stories.
- WID Testbed: Identification of hardware and software for experimentation. Identification of Shuttle processing sites where the wearable and wireless technology may be introduced. Identification of partners among the contractors. Identification of three case studies: Space Shuttle Main Engine (SSME) Processing, Sprayable Ablative Thickness Mapping for Solid Rocket Booster (SRB) Structures, and Thermal Control System (TCS) Blankets Processing. Identification of other support to expand experimentation. Acquisition of initial equipment. Continued testing of the acquired hardware and software.

Key milestones:

- 2000:
  - Spring: Initial research of hardware and software for WID done by students in the Applied Research in Industrial and Systems Engineering (ARISE) Center (NAG10-212).
  - June to December: Discussion of graphics to represent the message of P&HFE. Graphics and pamphlets are in the final stage of development.
  - September to December: Potential partners identified through various demonstrations and meetings.
  - October to December: Acquired hardware and software.
- 2001:
  - January to February: Testing of hardware and software.
  - February to June: Human factors study on the three selected cases.
  - End of August: Analysis of findings and recommendations.

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Participating Organization: Florida International University (Dr. M.A. Centeno)

Center for Applied Research in Industrial and Systems Engineering (ARISE)

ARISE established a combined research and educational program to attract and retain women, Hispanics, African Americans, and other individuals from minority groups to engineering. In the program, students have access to the tools necessary to start and complete industrial and systems engineering projects related to NASA operations and processes at KSC. Students participating in the program were:

- Exposed to and trained in NASA's mission
- Given seminars on a variety of issues, including realities of the workplace, diversity, and gender issues
- Asked to participate in applied research projects
- Instructed on the benefits of pursuing postgraduate studies to increase their chances to succeed in the workplace and to increase their stature as role models for future generations
- Given a 4-week onsite internship to become acquainted with the various KSC processes needed to complete projects
- Given a stipend during the academic year and summer terms

An important objective of this effort was to foster partnerships between Florida International University (FIU) in Miami, Florida, and NASA, as well as between FIU and local industry. The initial partners in this effort were FIU and KSC. FIU was the lead institution, and KSC provided steering guidance and implemented some aspects of the program. The initial timeframe of 2 years was extended for 1 additional year. During that time, various aspects of the partnership model were tested, rethought, and retested so it could become an appropriate model for industry-university partnerships. Several companies have participated in this partnership, with two of them participating every semester.

Key accomplishments:

- 1997: Established the center. Selected, purchased, and installed hardware, software, and other equipment. Developed a brochure and Web site (http://arisecenter.eng.fiu.edu) to advertise the program. Selected eight students for the program. Developed program activities.
- 1998: Purchased computer equipment and software. Conducted six seminars. Students visited KSC and participated in a 4-week summer internship. Curriculum integration: five projects were assigned; six students received credit in the Project Management class for the projects, and two students received credit as part of a technical elective course. Prepared and presented a proposal to local companies to encourage involvement. Continually updated the program Web site.
- 1999: Purchased computer equipment and software. Conducted 12 seminars. Purchased NASA videos for the center library. Continued

previously established programs. Established partnerships with three local companies. Supported six master's theses. Maintained the program Web site. Published several papers and presented them in national and international forums.
- 2000: Conducted 12 seminars. These seminars will continue in 2001. Continued established program components (see 1998 and 1999 key accomplishments). Continued partnerships with two local companies. Supported two master's theses. Continued Web site maintenance. Continued to publish papers and present them in national and international forums.

Key milestones:

- 1998: Project discussion, development, and conference. Continued industrial portfolio. Published papers and developed Web site.
- 1999: Project discussion, development, conference, and seminars. Published conference papers and a journal paper. Completed six master's theses.
- 2000: Project discussion and seminars. Published conference papers and a journal paper. Completed two master's theses. It is expected that partnership with local industry will continue.

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Participating Organization: Florida International University (Dr. M.A. Centeno and Dr. L.M. Resnick)

Cable and Line Inspection Mechanism (CLIM)

Biannual inspections of the seven slide-wire ropes used in the Emergency Egress System at Launch Pads A and B require inspection crews to visually verify the integrity of the wire ropes as the crews are lowered in the slide-wire baskets. Because of the type of wire ropes used as slide-wires (i.e., stainless steel with low carbon content), magnetic resonant devices normally employed to inspect the wire ropes are inadequate. This worker-intensive and time-consuming operation prompted a request to the Automated Ground Support Systems Laboratory to develop a stand-alone system for automated wire rope inspection. In addition, no method exists for inspection of the lightning wire ropes at each launch pad because of their inaccessibility.

The wire rope failures to be identified by the automated system, in accordance with the applicable operations and maintenance requirements document (OMRS File IV), are characterized by frayed strands, bird nesting, stretching, and corrosion. The wire ropes undergo periodic load testing and are man-rated by weighting the egress baskets with sandbags and sending them down the rope. Consequently, this is not a task for the automated system. The inspection teams rely on a visual inspection of the surface of the ropes with a cursory check of the rope diameter using a go/no-go gage every 10 feet. The targeted ropes were identified to have an inclination of no more than 45 degrees, a length of approximately 1,200 feet at 15 degrees, and a diameter of 1/2 to 3/4 inch.

A production unit was built that provides a real-time video image and diameter of the wire rope under test to an operator at the control station. Testing on a wire rope similar in angle and diameter to the egress system wire ropes shows a duration of 1,400 feet using 12-volt lead acid batteries. Data showing cable diameter is recorded to permanent memory in the on-board computer and can be downloaded to the control station posttest. Video is taped for playback using an off-the-shelf video recorder. Test runs for the unit were performed on a wire rope at Launch Pad A on three occasions.

Key accomplishments:

- 1998: Tested the prototype unit. Manufactured the production unit.
- 1999: Designed and built a production unit.
- 2000: Operated unit on a pad egress wire rope.

Key milestones:

- 2001: Turn over the production unit. Perform an acceptance test on the Launch Pad B slide wires.

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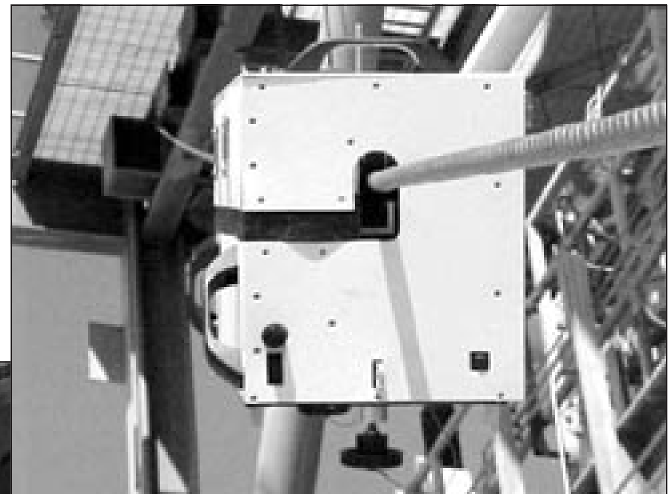
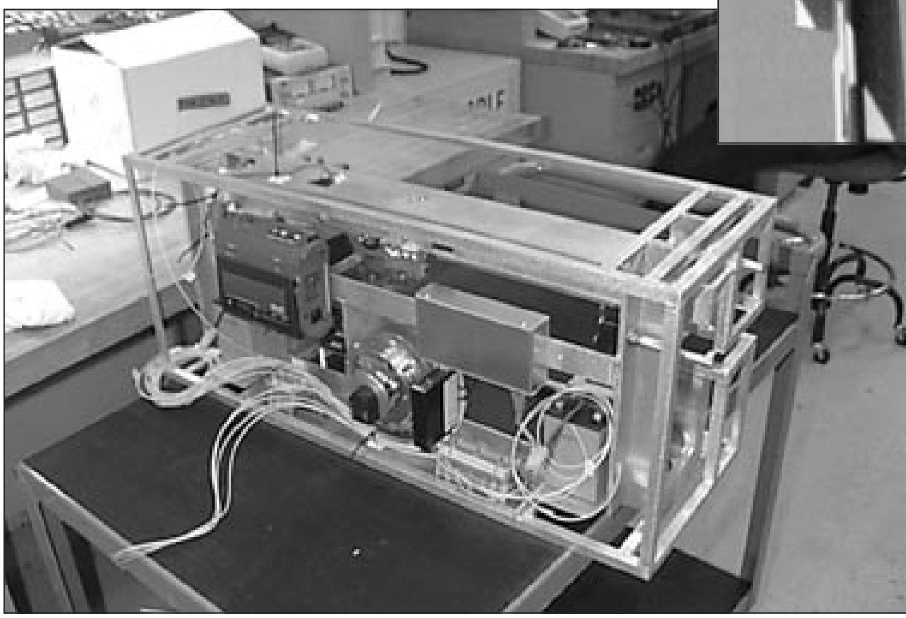
Participating Organizations: NASA YA-D2 (M.D. Hogue), NASA PH-J (K.M. Nowak), Dynacs Inc. (L.M. Parrish), and United Space Alliance (G. Hajdaj)

CLIM Unit Mounted on a Wire Rope





CLIM Unit Frame Without Covers

Defect on a Wire Rope

Space Shuttle Macro-Level Model

The complex nature of Shuttle ground operations with literally hundreds of interrelated deterministic and stochastic elements makes it a difficult system to analyze. On numerous occasions throughout the course of the Shuttle program's history, the need to ascertain the expected versus the planned flight rate and the effects of modification to some aspect of the flight or ground elements upon flight rate has arisen. In the past, most assessments assumed green-light schedules with little accounting for the occurrence of such things as launch scrubs, diverted landings to California, fleetwide groundings, and delays encountered in the various processing facilities.

A Space Act Agreement with the University of Central Florida was initiated in February 2000 to develop a macro-level simulation model of Space Shuttle processing at KSC. The primary objectives of this project are to act both as a proof of concept of the tools and techniques of process modeling and as a testbed for various improvement strategies to reduce the cost of operations, meet schedules, increase the flight rate, improve safety, and increase supportability. Discrete event simulation modeling was specifically chosen because it is flexible, able to model systems more precisely, capable of performing "what-if" analyses, and able to model the time-dynamic aspects of the system under study. Because this type of modeling typically needs probabilistic inputs as a requirement for validity, a considerable amount of data acquisition and modeling was required (figure 1). The conceptual basis for the macro-level model (figure 2) was also developed throughout the course of the project. The actual simulation model was built using the Arena simulation software package (figure 3).

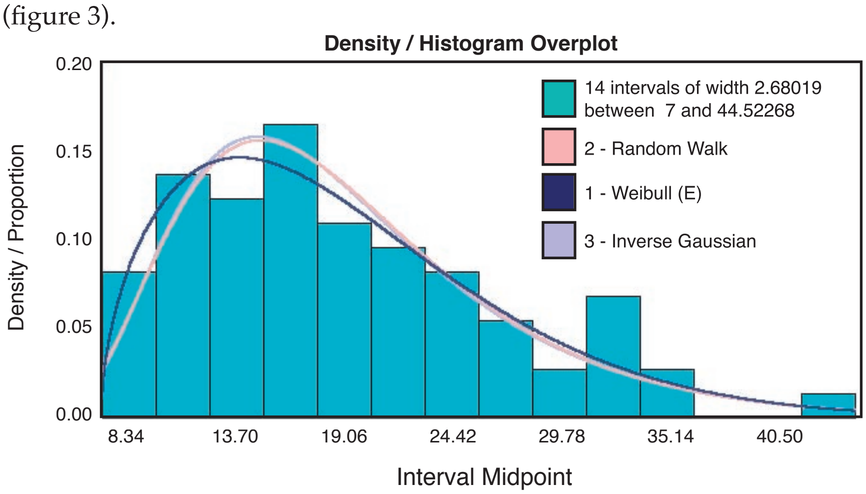


Figure 1. Data Modeling Using ExpertFit

The validated simulation model is now acting as a springboard from which numerous other opportunities are being studied. These include:

- Ground Processing
  - Support of manifest planning
  - Flight element, facility, and ground support equipment (GSE) resource utilization and capacity assessments
  - Processing of change assessments
  - Expansion to include payload, range, and critical KSC infrastructure elements
- Spaceport Engineering and Technology
  - Integration into overall spaceport modeling effort
  - Baseline for next-generation Reusable Launch Vehicle (RLV) comparison
  - Demonstration by new RLV models of ground processing dependencies on launch vehicle architecture, ground systems capacity, and configuration
  - Comparison of competing RLV designs with respect to operational cycle parameters both during and after the down-select process

Key accomplishments:

- Demonstrated tools and the approach for operations process modeling.
- Developed a valid simulation model of macro-level Shuttle processing.

Key milestones:

- Phase I, April 2000: Overall model structure development.
- Phase II, September 2000: Detailed development and validation.
- Phase III, 2001: Experimentation and utility development.

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Participating Organization: University of Central Florida (Dr. M. Mollaghasemi and Dr. G. Rabadi)

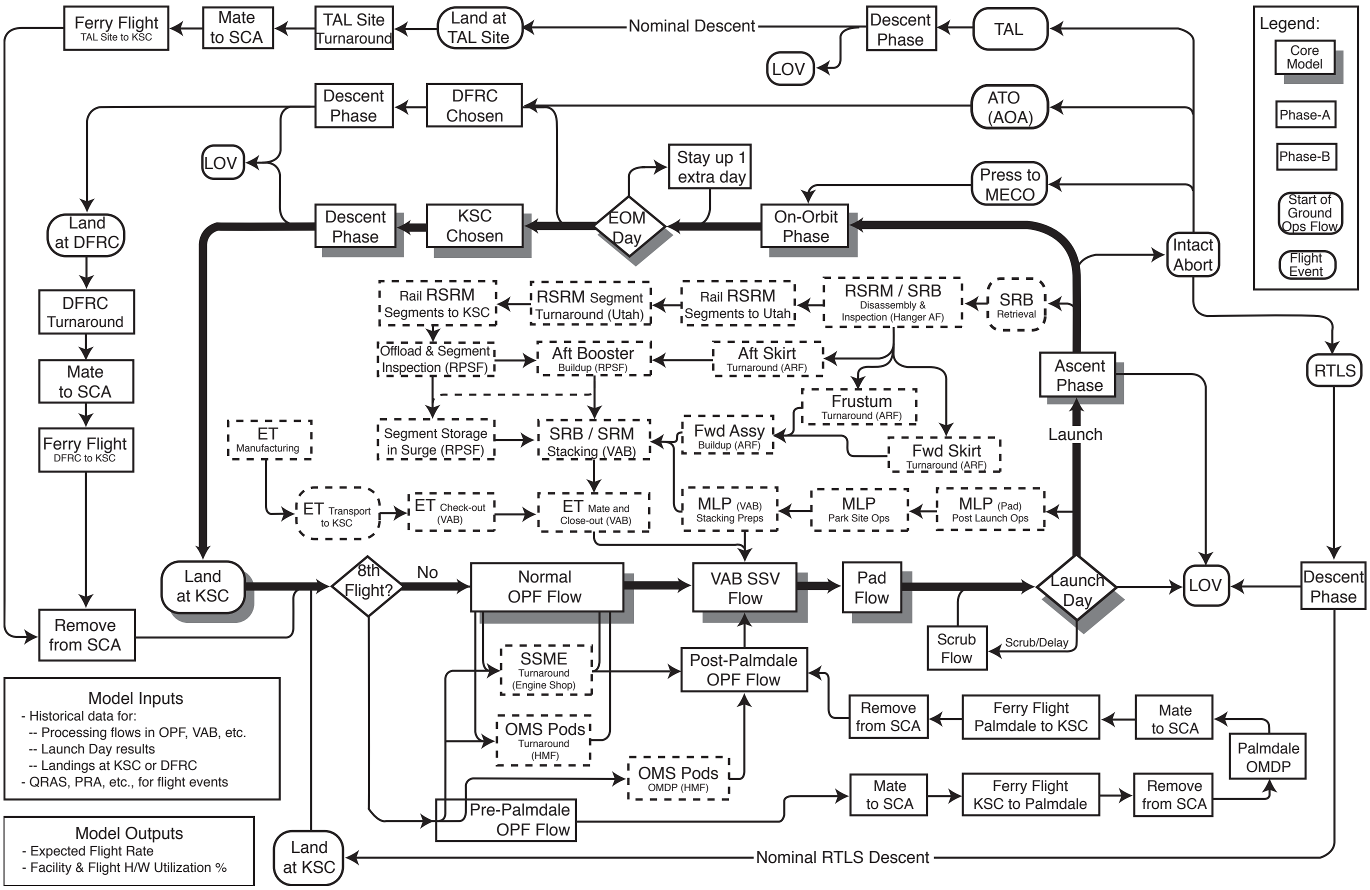


Figure 2. Conceptual Flow Diagram

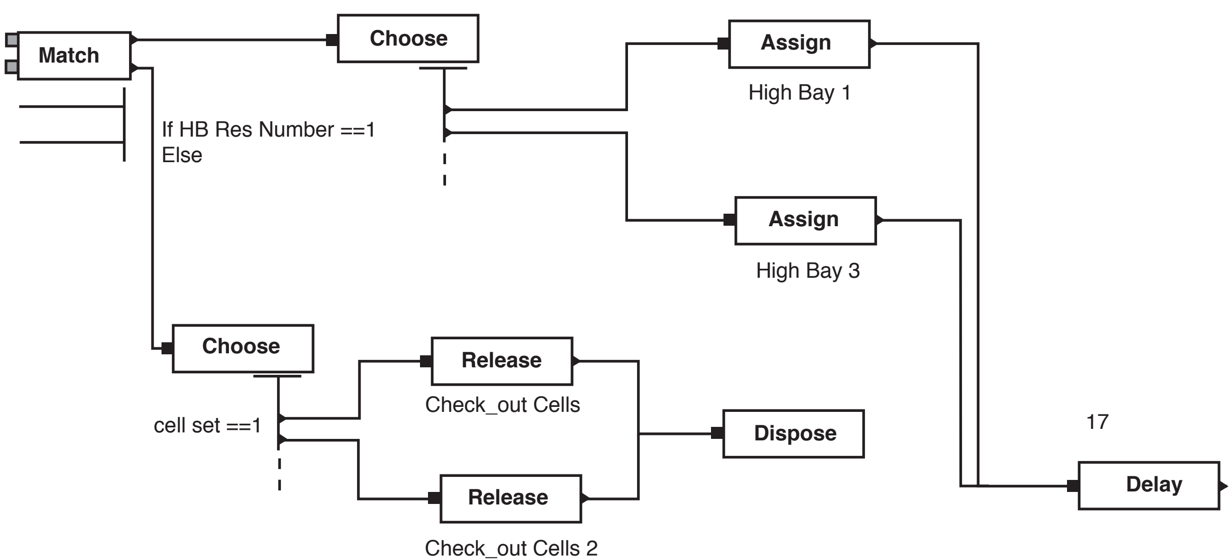


Figure 3. ET Mate and Closeout Portion of Simulation Model in Arena

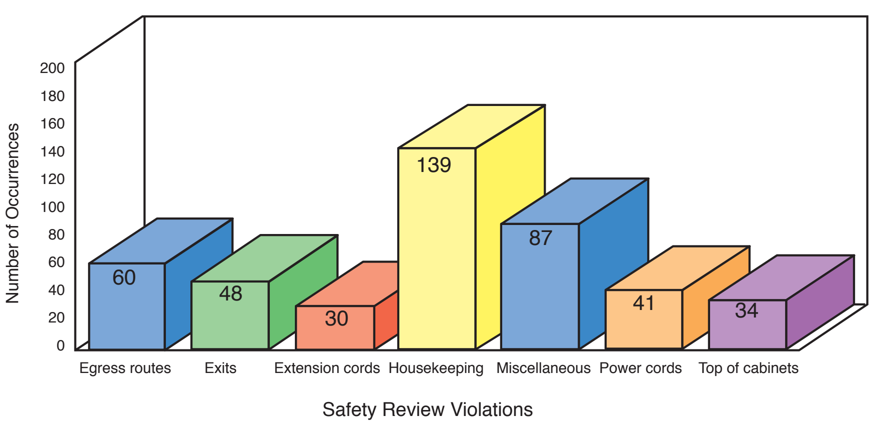
NASA/KSC Hazardous Observation and Abatement Tracking System

The Hazardous Observation and Abatement Tracking System (HOATS) was developed to support OSHA CFR 1960 and the NASA Policy Document making supervisors responsible for the safety and welfare of their employees. A Web-based application was needed that could record, review, analyze, and report the results of the safety walk-down inspections. HOATS was created to satisfy these requirements and show the NASA/KSC proactive approach to safety.

Formerly, safety inspections in and around the workplace were the responsibility of NASA's safety organization. Safety inspectors performed the safety walk-downs and recorded the results on a form. The form required the inspector's name, date, name of the responsible person, organization, mail code, location, safety issues, and corrective action (if needed). The completed forms were given to a designated individual to enter into an Excel spreadsheet. This data was then compiled for reporting and trending purposes.

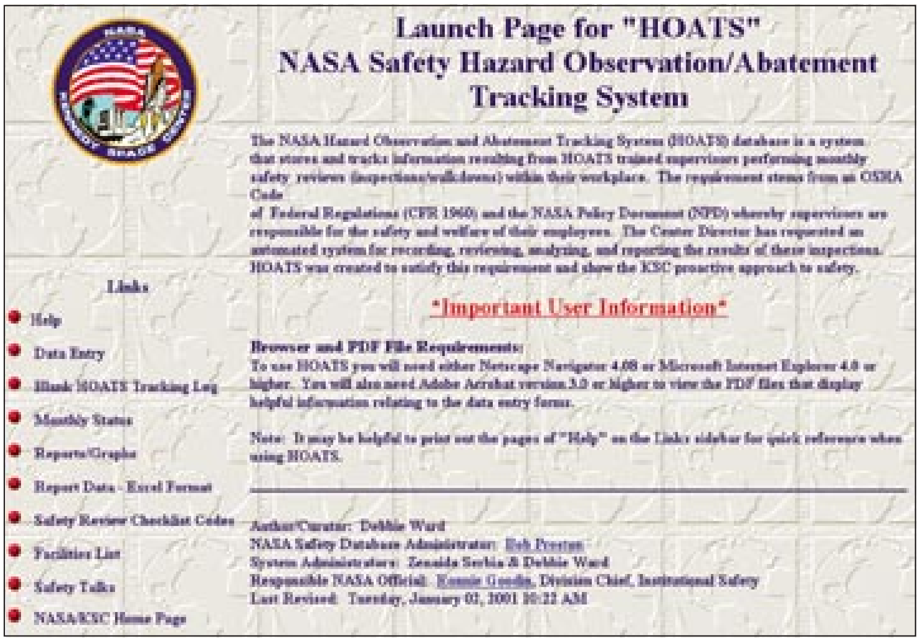
Every employee at KSC is accountable for safety. New safety requirements now place responsibility on all NASA supervisors at KSC to perform monthly safety inspections within their work areas.

The significance of this project is that it provides supervisors the capability to input their safety walk-down data via the Web. Access to HOATS is controlled by user name and password. The HOATS application is a data management and reporting system designed to record monthly safety inspections and generate reports and graphs from this data. Many reports may also be viewed as Excel spreadsheets for additional calculation and trend analysis. HOATS has been operational for 2 years and upgraded with new and modified reports and software.

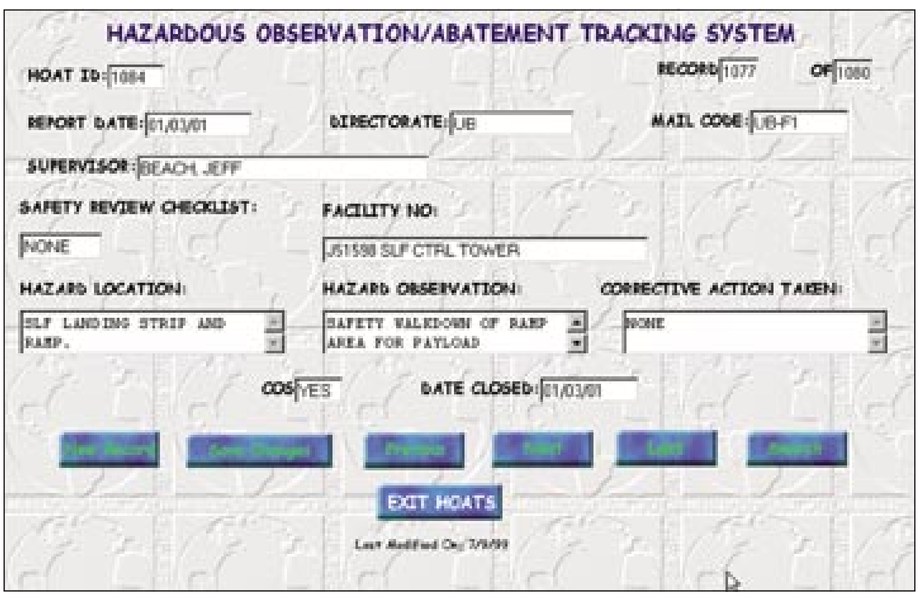


One of Many Graphs That HOATS Offers From the Reports/Graph Link

The HOATS home page gives users a brief introduction to the system, background, and necessary browser requirements. There is also a Links Bar with hyperlinks to a help page, data entry page, monthly status page, reports, and graphs. When the user clicks on the Data Entry link, a JavaScript calls up the Maintain application bringing the user to the HOATS application main form. From this form, the user may employ buttons to scroll through existing records, enter a new record, or go to a Search form. The Search form enables the user to search existing records based on one of four criteria: supervisor, directorate code, mail code, or report date. A key advantage of this search capability is that it simplifies editing of records by grouping together records of a specific criterion. The New Record button brings up the HOATS Add/Entry form where the supervisor enters inspection data following the monthly safety walk-down. The Monthly Status link on the HOATS home page invokes another JavaScript that runs a monthly report. The user chooses a month from a dropdown box, and an HTML window displays the number of safety reviews performed that month by the supervisor for each directorate. The Monthly Status shows only the number of safety walk-downs performed in each directorate and does not list details such as safety issues, locations, etc. The Reports/Graphs link allows the user to choose from several real-time reports and graphs. These reports and graphs are much more detailed, with many of the reports



HOATS Home Page



HOATS Application Main Form

drilling down to the actual record. Reports with archive data are also available for trending purposes.

Key accomplishments:

- September 1998: Developed an application using Cactus (now called Maintain) to capture and store the data and Web Focus for report and graph generation. Microsoft FrontPage was used as the Web front end.
- November to December 1998: Tested the prototype and made modifications following supervisor training led by NASA Safety.
- January 1999: HOATS became operational and went on-line at KSC.
- May 2000: Demonstrated the HOATS application at a Technical Summit in Palm Desert, California.

Key milestone:

- 2001: Establish a link with the Goal Performance Evaluation System (GPES).

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Participating Organization: Information Builders, Inc. (D. Haug and W. Villegas)

Insight – A Web-Based Data Reporting and Collection System

A downsized workforce and the conversion to a performance-based contract challenged NASA's mandate to process the Shuttle efficiently. In response, the Insight System is being developed (figure 1). This data access and database system allows NASA's reduced rank of engineers to more efficiently monitor contractor processes and validate the capability and stability of those processes. The system uses cutting-edge, Web-enabled technologies and unique data warehouse architectures to assist engineers.

The Insight System is being developed so the Government can obtain the insight needed to effectively assess a contractor's performance. The system design was based on the following requirements:

- Commercial off-the-shelf (COTS) hardware and software (figure 2) (minimize maintenance and development cost)
- Access to contractor data for surveillance activities
  - To validate contractor metrics
  - To build metrics not currently provided by the contractor
  - To identify metrics being collected but not needed
- Access to NASA data for surveillance activities
- Minimize data collection efforts through data sharing (team interdependence)
- Provide access to data/information without controlling it
- Automate report generation and notification
  - Reports available in 15 seconds or less
  - Notification when report indicates an out-of-limit condition
- Reports
  - Available on-line and on demand
  - Flexibility in data formats
  - Modular (cut and paste)
- Minimize resources required to develop, implement, and maintain the Insight Machine

This system makes Web-based reports by the Core Process available to users through their Web browser. The user has a choice of looking at the report through the browser or downloading the data in the report directly into an Excel format for further analysis. The system also allows selected individuals to run ad hoc reports in real time. These reports may contain any combination of data from the following servers:

- SPDMS (PRACA, IOS, ASRS, ALRUTS, OMRSD)
- Amdahl (CMDS)
- USA First Time Quality
- PK NASA Engineering (PITA Sheets)
- USA PeopleSoft and MAXIMO

Because of its flexibility in collecting and integrating data from a variety of sources, this system is now being upgraded to allow users to develop additional engineering reports, over and above the initial metric requirements. It also allows conversion of the collected data into different types of databases. That is to say that SQL, Oracle, Access, and ADAbase data can be collected and converted into a single data type such as SQL or Oracle. Forms can also be generated to collect data not presently collected by other sources.

Key accomplishments:

- 1997: Established an implementation team. Initially deployed software to prove/demonstrate initial concepts (PRACA). Developed preliminary reports to stimulate user thoughts on metric and report development.
- 1998: Started development of automated metric reports for the user community. Placed developed reports online. Connected additional databases (First Time Quality, CMDS, IOS). Trained users on COTS software to allow for report generation by users. Investigated data warehousing to improve system performance.
- 1999: Identified and connected additional databases (PK, Maximo). Developed the NASA warehouse capability. Made a decision to provide customer development services.
- 2000: Refined customer metric report requirements. Identified and connected the PeopleSoft database. Developed the NASA data warehouse capability and upgraded the hardware. Implemented data collection development. Supported other customer requirements (CLCS, Safety, Close Call Accounting, and Project Management). Refined the Core Process Reporting Environment. Started development of additional engineering and operational reports. Completed the strategic planning effort and determined the next milestones.

Key milestones:

- 2001: Implement Strategic Planning recommendations. Identify additional databases and connect to them. Develop the Report Builder Page prototype. Develop the Manage Reporter Environment Home Page to replace the existing Core Process Home Page.

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Participating Organization: Information Builders, Inc.

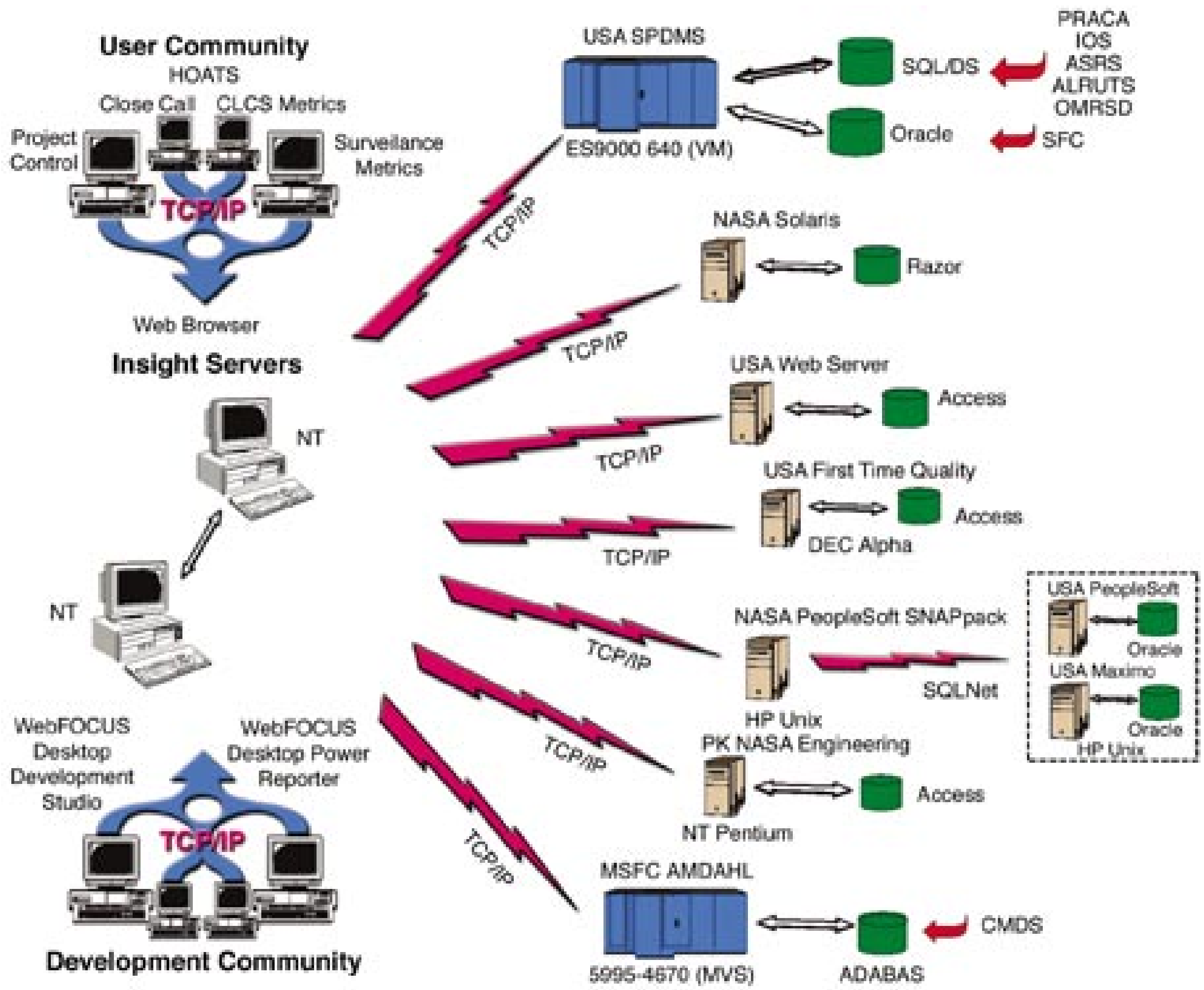

Figure 1. Insight System Information Pipeline

Figure 2. COTS Product Suite

Development of a Methodology and Hardware To Conduct Usability Evaluations of Hand Tools

In the past, a great deal of research was conducted to test the physical attributes of hand tools, including tests of hardness, load, heat tolerance, flammability, and solvent damage. This research is performed to determine how the environment and the user affected the tool. Much less research has been done in the area of usability engineering of hand tools. Usability engineering is concerned with the effects the tools have on the user in terms of performance, comfort, and the risk of injury. This research focused on developing the methodology and the hardware to conduct usability evaluations of hand tools with the goal of reducing foreign object debris (FOD), which may also result in reduced risk of injury to the user. FOD, which is the debris left in or around flight hardware, is an important concern during the processing of space flight hardware. Just one small screw left unintentionally in the wrong place could delay a launch schedule, increase the cost of processing, or cause a potentially fatal accident.

Technician at Usability Testing Board

The usability of new hand tools was determined based on the objective indicators of performance (the number of parts dropped) and efficiency (time to install a part). In addition, subjective data was collected through posttest questionnaires, which related to the ease of use, the force required, comfort levels, the likelihood to drop parts, and the physical characteristics of the hand tools. To validate the methodology, participants were tested while performing tasks representative of the type of work that might be done when processing space flight hardware. Test participants installed small parts onto the usability testing board using their hands and two commercially available tools.

The methodology and usability testing board can be used to test hand tools formally to show statistically significant differences in performance. It can also be used informally to gather information for new designs or to compare tools quickly. It allows the user to try the tool in a variety of positions in a controlled environment where there can be no damage to flight hardware. Tools can be tested for several purposes, including increasing performance and efficiency and reducing risk of injury to the user.

Key accomplishments and milestones:

- 2000: A testing methodology and a hand tool usability testing board were developed. The methodology and hardware were used successfully by Boeing to develop and test the usability of a prototype hand tool that was designed to reduce FOD while installing small parts near the flight hardware.

- 2001: The methodology and usability testing board are available for use in the development and testing of hand tools.

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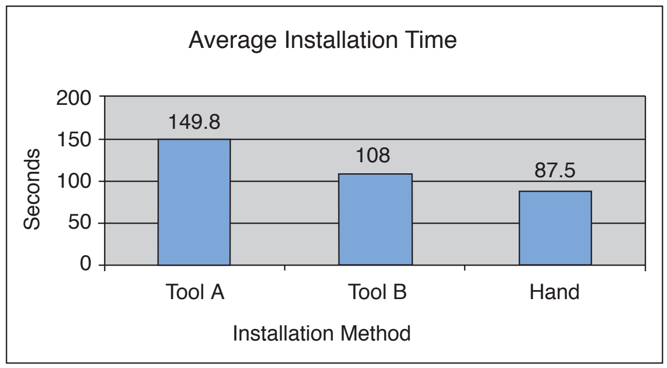
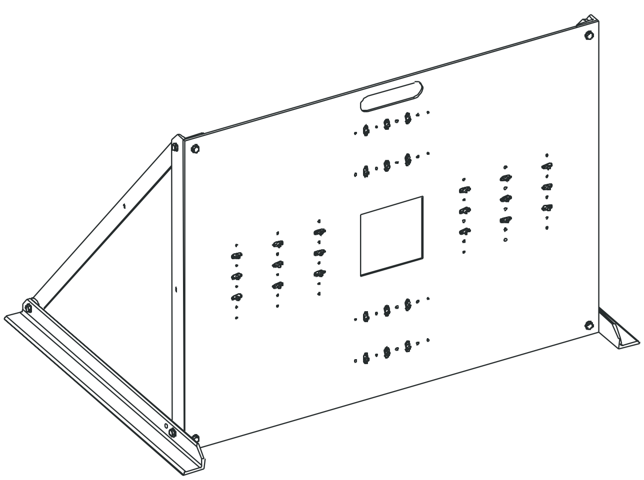
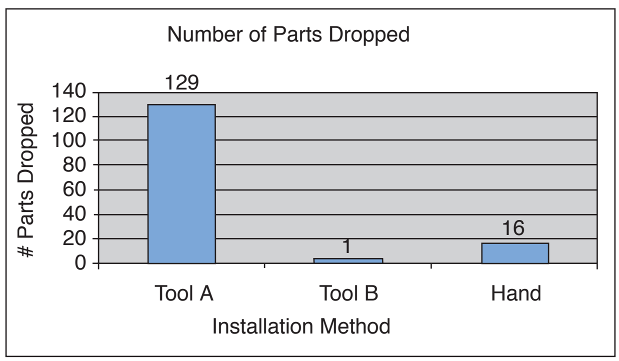
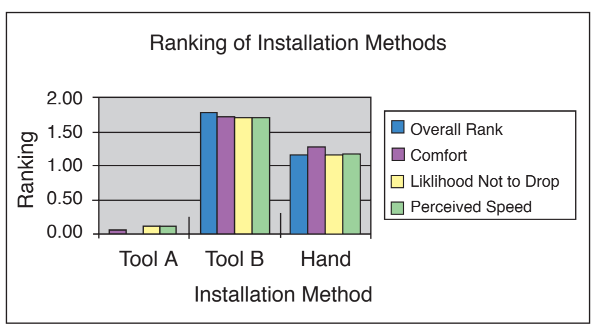
Participating Organizations: YA-D1 (A.C. Littlefield), YA-F2-P (D.E. Rowell, K.L. Boughner, J.P. Niehoff, R.A. Breakfield, and R.P. Cartier), University of Central Florida, and Boeing (F.T. Chandler)





Hand Tool Usability Testing Board



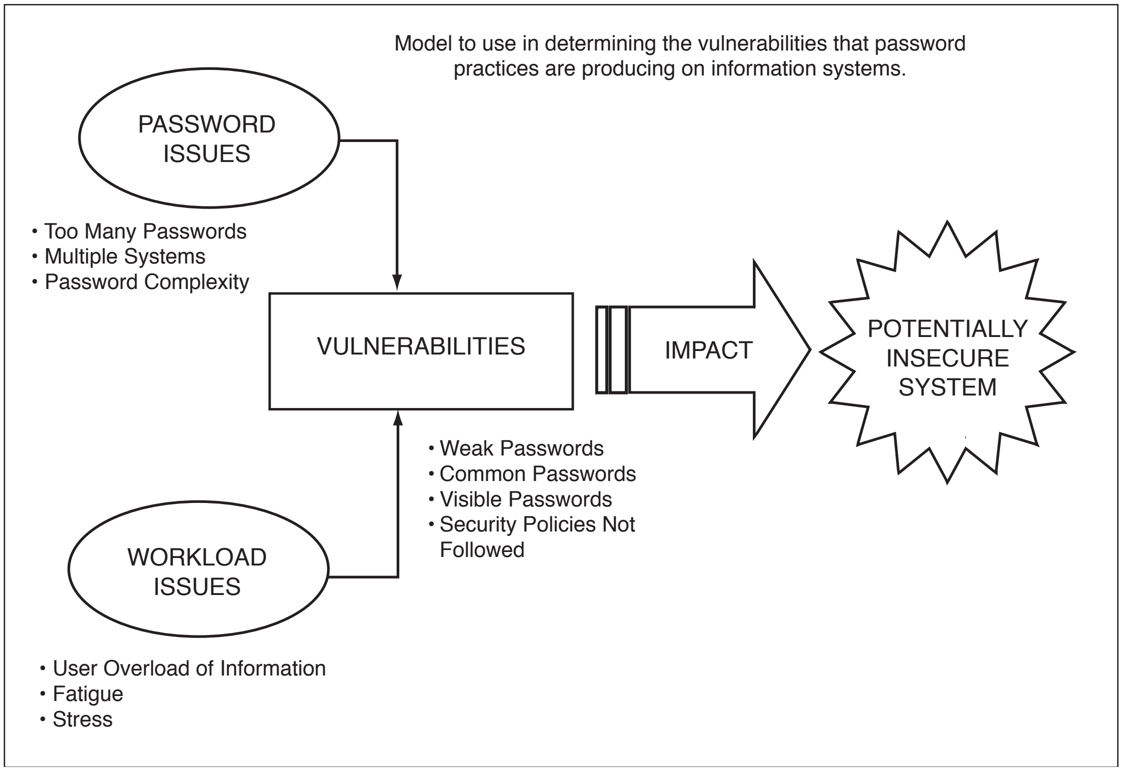


Development of Human Factor Guidelines for Authentication With Passwords

The world has been revolutionized by the abundance of information that makes its way into the daily lives of individuals. With the expansion of technology, preoccupation with information as an individual, organizational, and societal resource is stronger than it has ever been in history. Users of technology are at risk of overloading human memory limitations as the number and complexity of passwords, user ID's, and other electronic identifiers increase. The role that understanding human factor (HF) limitations plays in the development of a security policy from a password authentication standpoint is in minimizing the demands that passwords place on the human memory system. The problem is defined to be "the identification and management of vulnerabilities created by the proliferation of professional and personal authentication needs in information systems." This research focused on the link between password and workload issues relating to human memory limitations and addressed the human side of information security through the development of an HF systematic approach to security programs. This research helps those who design security policies by providing applicable and simple guidelines for information system users resulting in the following contributions:

- Reduced vulnerabilities produced by information systems within organizations
- Increased trust that can be placed in the users of information systems

The objective of this research was to measure and validate the impact of password demands as a means of authentication. Through observational analysis, organizational policy, and retrospective analysis, a model was created to predict the effects of a particular set of vulnerable conditions on the likelihood of error in an information system. This research evaluated how passwords and humans affect the security of information systems and how human error in information security can be reduced or eliminated in systems. The model helps HF practitioners and information technology (IT) professionals determine the vulnerabilities that password practices are placing on their information systems (see the figure). The model enables researchers to identify specific password issues and workload issues that make a system vulnerable to security breaches. This research allowed the development of HF guidelines for authentication with passwords to help mitigate the risks that result when password demands exceed human capabilities. The HF guidelines for passwords enable an individual to choose a strong password (meaningful to the user) that is acceptable to the IT community yet does not exceed human memory limitations. This promotes organizational security by making information systems more difficult for hackers to breach. Password guidelines that are within human memory limits help users follow the organization's security policies and avoid vulnerable practices such as using the same password for multiple systems or writing



System Vulnerabilities Model

passwords on paper. The findings of the experiments indicated that adoption of the developed guidelines can significantly reduce system vulnerabilities from human error associated with passwords. Through simple password guideline changes and employee password security training, organizations can better guard against human error while maintaining safe practices for user authentication that guard against external threats. The systematic HF approach to security programs presented as an outcome of this research is a solution to one of the challenges brought about by the ever-increasing presence of technological breakthroughs in organizations.

Key accomplishments:

- November 1999: Analyzed preliminary research (password survey and experiment).
- December 1999: Developed model to determine vulnerabilities that password practices are producing on information systems.
- May 2000: Completed primary research analysis of the case study experiments and information security subject matter expert survey.

Key milestone:

- July 2000: Completed development of human factor password guidelines.

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Participating Organizations: NASA KSC, University of Central Florida, SEBA Solutions Inc., and Mississippi State University

Human Factors Analysis Leads to Breakthrough Designs in Foreign Object Debris Prevention

A human factors process failure modes and effects analysis completed in 1999 on the Space Shuttle Dome Heat Shield Installation Process found there was a high potential for small parts to be dropped inside the orbiter during installation and removal and to become Foreign Object Debris (FOD). If FOD is not recovered, the probability of damage to the orbiter during flight is increased. No satisfactory method or tool existed to prevent dropping parts. Consequently, significant time spent locating lost or dropped parts has affected schedules and continues to pose problems for Shuttle processing. These problems occur in all facets of aerospace processing and aviation. Research has attributed 6.5 percent of commercial inflight incidents to the loss of small parts. Thus, prevention of FOD is crucial, and the reduction of dropped parts is a critical element in the prevention of FOD.

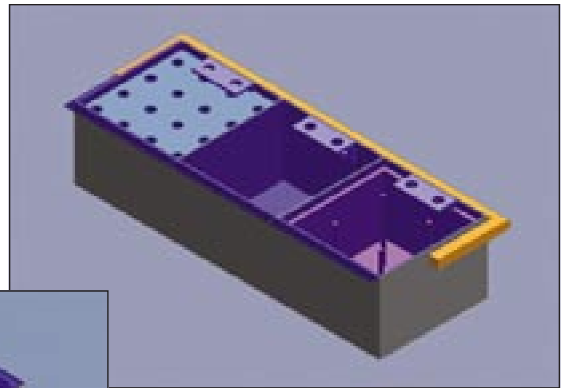
Technician Tests Fastener Starter by Simulating Hardware Installation Tasks

FOD reduction in Shuttle processing was the catalyst for the development of the Fastener Starter. The Fastener Starter is a small, lightweight, ergonomically designed tool that securely holds small parts (e.g., screws, bolts, washers, nuts, and other fasteners) and combinations of parts during their installation into and removal from space flight vehicles. The tool's method of firmly gripping and releasing hardware without the use of magnetics and its ability to accommodate a variety of part sizes, types, and hardware combinations are just two of the features that make the Fastener Starter unique.

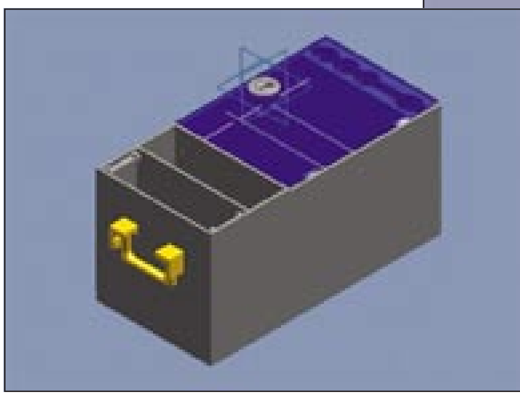
The Fastener Starter was developed by incorporating task requirements, user preferences, flight hardware constraints, and lessons learned from evaluations of currently available tools. Technicians simulating hardware installation tasks tested the tool. The test evaluated the tool's performance (parts dropped) and the technician's efficiency and subjective rating of the tool. The usability testing verified operational readiness, reliability, and user satisfaction with the tool. Of those technicians tested, 90 percent preferred use of the Fastener Starter over the current hand installation methods.

Key accomplishments:

- Fastener/Starter/Remover (patent pending).
- Tote-All Bin/Portable Hardware Box concept (patent pending).



Bin



Portable Hardware Box

Fastener Starter Holding a Screw

Fastener Starter Open

Key milestones:

- Phase I: Data collection (design requirements, constraints, and functions).
- Phase II: Concept development.
- Phase III: Prototype development.
- Phase IV: Final design requirements, prototype, and report.

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Participating Organization: Boeing (F.T. Chandler, M. Arnett, M.E. Banks, H.L. Garton, R.L. Griffin, K.M. Krivicich, M.E. Shaw, and W.D. Valentino)

Vision Spaceport Model Development

An analysis of the world's space transportation systems reveals issues with excessive costs, continual launch schedule delays, and failure of the systems to achieve aircraft-like capability. None of the systems have yet achieved a level of payload delivery capacity needed to open space as a routine, affordable destination. Worldwide, the delivery tonnage of payloads to Earth orbit has failed to increase in accordance with many business model predictions for over 10 years, which reflects the impact of extraordinary space transport costs. System affordability and increased spaceport payload throughput is essential to the opening of space as a viable business frontier.

With its mission of Space Launch Operations and Spaceport and Range Technologies, KSC initiated a Joint Sponsored Research Agreement to examine generic launch site operations and infrastructure cost-driving factors. This agreement, wherein the Government, industry, and academia partners contribute resources to accomplish the project, has taken on the task of influencing spaceport system-design interfaces with launch vehicles of the future. The partnership identifies candidate technologies that have the potential to enable revolutionary spaceports of the future to provide effective and affordable space transportation.

The partners formed a consortium known as the Spaceport Synergy Team that consists of launch site analysts and engineers who have released an initial operations-cost core model. This innovative model incorporates a database encompassing historical performance of key launch systems. Elements of strategic investments in spaceport/vehicle interactive technologies that hold promise to enable systems and operations that lead to affordable space transportation are being identified.

As the model matures during 2001 into a commercial product, design criteria for emerging concepts can be entered and compared to known operations data embedded in the model database. Estimates of space transportation infrastructure and operational performance are then calculated and presented in terms of capital investment costs, recurring costs, and flight rate capability.

For a wide variety of advanced launch vehicle concepts and technologies, the model is designed to identify, at a top level of resolution, the magnitude of launch site facility infrastructure and acquisition costs, operational work force size and associated cost levels, vehicle processing cycle times, and estimates of system flight rates. The core model is comprehensive in scope and includes 12 generic spaceport functional modules: payload cargo processing, traffic/flight control, launch facilities, landing/recovery, vehicle turnaround, vehicle assembly/integration, vehicle depot maintenance, spaceport support infrastructure, concept-unique logistics, operations planning and management, expendable elements, and connecting infrastructure/community services.

Key accomplishments:

- 1998: Modeling (prototype development and launch system templates), data collection, and visualization technology proof-of-concept.
- 1999: Implementation of modeling methodology to a working application and visualization application moved to a PC platform.
- 2000: Release 1 of the Vision Spaceport Strategic Planning Tool completed for independent assessment by Government, industry, and academia. Patent application completed for the modeling methodology. Technology Assessment completed in support of NASA's Space Solar Power (SSP) Exploratory Research and Technology (SERT) program. Candidate spaceport technology white papers evaluated by the spaceport technology assessment method. Customer/stakeholder interviews completed to determine desired spaceport attributes. Utilized the prioritized spaceport attributes and design features to perform the assessment.

Key milestone:

- 2001: Continue to mature the Vision Spaceport Strategic Planning Tool by extending the model output "figures-of-merit" indexes to quantifiable cost and cycle times. A second release is planned for this year.

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Participating Organizations: Ames Research Center, Boeing, Command and Control Technologies Corporation, Lockheed Martin Space Systems, and University of Central Florida/Institute for Simulation and Training

Logistics Spares Model for Human Activity in Near Earth Space

The next generation of NASA missions includes sending humans to the Moon, asteroids, Mars, and beyond and returning them safely to Earth. Various mission architectures are being developed for this class of mission, and some missions require the crew to be away from Earth for 2 to 3 years. Extended-duration missions like these will require an unprecedented degree of crew self-sufficiency. In order to achieve this, the hardware must be both highly reliable and maintainable. Hardware may include spare parts for surface exploration, habitation, and the spacecraft.

A critical aspect of hardware maintenance is to ensure the correct spare parts are available to the crew. The long duration of these missions, coupled with the lack of opportunity for resupply and constrained mass and volume allocations for spares, makes this a difficult problem. Selecting the correct mix of spares may well make the difference between mission success and failure.

This project develops a methodology and a model that will allow NASA to estimate the mass and volume of spares required for a given level of system performance. This in turn will help to determine if the current assumptions concerning launch vehicle sizing are correct and where to focus technology improvement efforts to the greatest advantage [e.g., improved line replaceable unit (LRU) failure rates, reduced LRU mass and volume, or alternate maintenance concepts]. The methodology is flexible enough to accommodate a variety of human missions in Near Earth Space.

The contractor, the Logistics Management Institute in McLean, Virginia, has developed and delivered a model that estimates the spares requirements for such missions utilizing key mission parameters, such as the duration of mission phases, systems to be supported, configuration of those systems, and characteristics of individual system components. The model uses an item-specific database extracted from Johnson Space Center's Mars Reliability Block Diagram Analysis database. Future modeling efforts may include streamlined interfaces or model enhancements to include alternate maintenance or supply concepts.

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Participating Organization: Logistics Management Institute (R. Kline, T. Bachman, and T.J. O'Malley)

Payload Ground Handling Mechanism (PGHM) Project: J-Hook Automation Phase

The J-hook study is the next phase in the PGHM Automation Project. The PGHM is a large steel structure that provides gross movements as it holds the payload and rolls toward the orbiter. The J-hooks are mounted to the PGHM with the payload supported by a hook at four points. The hook provides finite movement for final installation, with a 3-inch range and 0.005-inch accuracy. The PGHM was automated in 2000 and is operational at Launch Pad B; Pad A will be done at the next available opportunity. Options to automate the current J-Hook system are now being considered.

The current system's moving power is operated by a technician "controller" at a manual hydraulic control panel some distance from the J-hook, where another technician "spotter" gives verbal feedback on the hook position. The on-site move director assimilates all the ongoing communications and gives the commands for movement of the hooks. This operation is communication- and manpower-intensive, requiring as many as 16 J-hooks and 8 control panels for some payload configurations.

The current system also has gaseous nitrogen accumulators to give the hydraulic system some flexibility "compliance" so damaging reaction loads will not be applied by the J-hook system to the payload or orbiter during loading. These reaction loads can be caused by wind sway or overextension of a hook. The hydraulics are operation- and maintenance-intensive.

Options to be investigated for improving the system include giving control of the J-hook movement to the "spotter" by means of automated or manual local controls, with the move director having overall control. This would free up the human "controller" at the existing remote manual control panel. Replacing the existing J-hook hydraulic system with electromechanical actuators for movement and using pneumatic pistons for compliance would eliminate the power hydraulics.

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Participating Organizations: NASA Shuttle Processing Directorate, United Space Alliance, and Dynacs Inc.

Range Technologies

The space launch range element consists of the range support facilities and equipment required to provide control, supply measurement data, and ensure safety of launch and test operations. Examples include range safety analysis data processing equipment, telemetry reception and processing equipment, command destruct systems, radar systems and displays, optical tracking and recording equipment, control centers, and communications systems.

Activities/focus areas include the following:

- Weather Instrumentation and Systems
- Space-Based Range Systems
- Spaceport (Ground-Based) Range Systems
- Decision Models and Simulation
- Range Information Systems Management

The goals and objectives of the Range Technologies include the following:

- Develop range systems that safely reduce cost while increasing launch and landing opportunities
- Develop range systems that safely support multiple vehicles operating simultaneously
- Develop range systems that support safe operations to multiple Spaceports

Challenges include determination of influencing phenomenon and sensor development, accuracy and resolution of sensors and instrumentation, optimization of functional allocations, distributed multiprocessing and supercomputing environment, and optimization of network architecture

For more information regarding Range Technologies, please contact Richard Nelson, (321) 867-3332, *Richard.Nelson-2@ksc.nasa.gov,* or Edgar Zapata, (321) 867-6234, *Edgar.Zapata-1@ksc.nasa.gov.*

Lightning Launch Commit Criteria

Launch vehicles are vulnerable to triggered lightning strikes like the one that destroyed the Atlas-Centaur 67 in 1987. To prevent recurrence of that unfortunate event, a set of lightning launch commit criteria (LLCC) was established. These rules must be satisfied by clear and convincing evidence before a launch is permitted. The rules prohibit launching through or near a variety of different kinds of clouds that may be electrically charged. These rules are necessarily extremely conservative because atmospheric electricity is not well understood. This conservatism sometimes restricts launching when conditions are actually safe.

The LLCC project will collect data using a specially instrumented aircraft and ground-based instrumentation to improve the knowledge of how electric charges behave in the cloud types specified in the rules. With this knowledge, the rules will be revised to improve launch availability while maintaining or even increasing safety. The aircraft will carry a full suite of cloud physics instruments plus a unique set of six electric field mills. The field mills will permit a direct measurement of the vector electric fields in clouds as a function of the size and shape of the cloud particles and the relationship in space and time of the cloud to its associated thunderstorm.

Key accomplishment:

- June 2000: The first field campaign collected several complete sets of data in thunderstorm anvil clouds.

Key milestones:

- February 2001: The second field campaign will collect data in thick clouds associated with cold fronts.
- June 2001: The third field campaign will complete the collection of data in the field.
- June 2002: A presentation will be made of proposed revisions to the operational LLCC.

Contact: Dr. F.J. Merceret (Francis.Merceret-1@ksc.nasa.gov), YA-D, (321) 867-0818

Participating Organizations: More than 50 people from at least 11 organizations are participating in this project. Major scientific contributors include Marshall Space Flight Center, National Center for Atmospheric Research, University of North Dakota, National Oceanic and Atmospheric Administration (NOAA) Environmental Techniques Laboratory, Air Force Research Laboratory, University of Arizona, and NOAA/Hurricane Research Division.

University of North Dakota Citation II Cloud Physics/Field Mill Aircraft
During a Field Mill Calibration Flyby at the Shuttle Landing Facility, June 2000

Evaluation of a High-Resolution Numerical Weather Prediction Model Over East-Central Florida

Weather support of operations at KSC and Cape Canaveral Air Force Station (CCAFS) requires detailed forecasts of winds, clouds, ceilings, fog, and hazardous weather such as thunderstorms. Forecasting these parameters for KSC/CCAFS is a challenging task since the Central Florida facilities are located in an environment where there is an absence of significant large-scale forcing, such as cold fronts during much of the year. Under these conditions, local factors such as land/water boundaries (see figure 1), land use, vegetation type and density, and soil moisture play a dominant role in determining the short-term evolution of weather conditions. Guidance from current-generation global and regional weather models is of limited value for these forecast problems because these models do not have sufficiently fine spatial resolution to resolve small-scale features that affect wind, temperature, and moisture patterns over East-Central Florida.

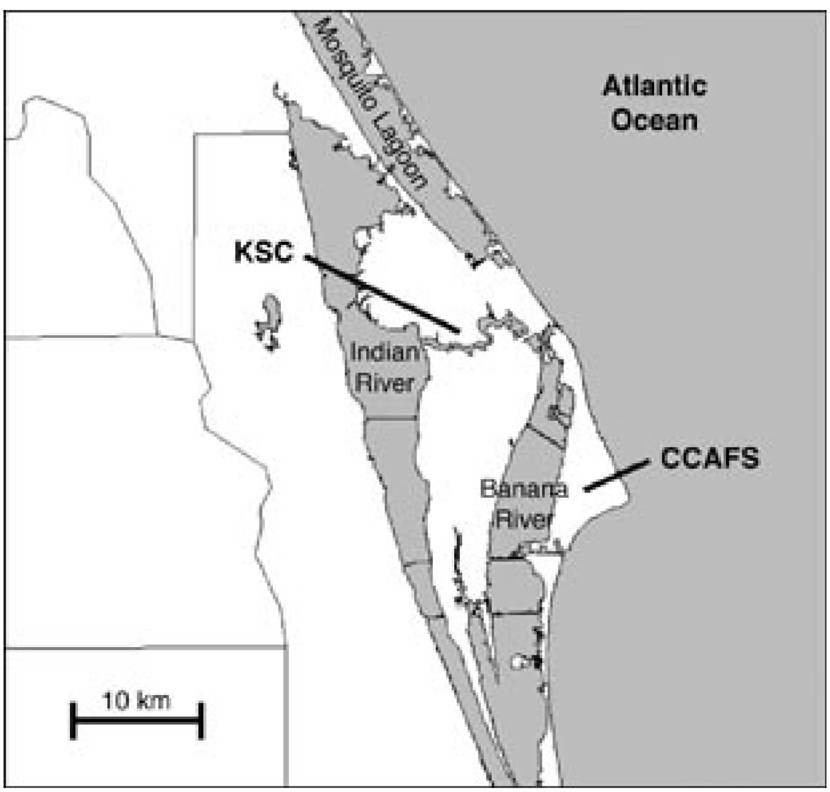

Figure 1. A Plot of KSC and CCAFS Illustrating the Complex Land-Water Geography That Influences Local Weather Patterns, Particularly During the Summer Months (Shaded Regions Denote Bodies of Water)

During 1999 and 2000, the Applied Meteorology Unit (AMU) evaluated a high-resolution configuration of the Regional Atmospheric Modeling System (RAMS) contained within the Eastern Range Dispersion Assessment System (ERDAS). ERDAS is designed to provide emergency response guidance for operations at KSC/CCAFS in the event of an accidental hazardous material release or an aborted vehicle launch. In addition, RAMS output can serve as guidance for operational weather forecasters at KSC/CCAFS. By running RAMS at sufficiently high spatial resolution, the model has the capability to resolve the interactions between river and sea breezes across KSC/CCAFS.

The RAMS evaluation consists of both an objective and subjective verification strategy. The objective verification involves computing model point error statistics at a number of observational sensors. However, when used alone, objective verification is not sufficient to quantify the overall value that fine-scale weather models add to the forecast process. Subjective verification is included to quantify the added value of model forecasts for specific weather phenomena of concern (such as sea breezes, precipitation, and thunderstorms) during ground and spaceflight operations.

Figure 2 shows an example of a RAMS forecast wind field under a light and variable wind regime on 18 August 2000, depicting the detailed interactions between the river and sea breezes across KSC/CCAFS. Note the convergence of winds over KSC created by the interacting river and sea breeze circulations. This case is an example of the many sea breeze forecasts that were verified on a local scale to determine subjectively the quality of RAMS wind forecasts. The results from this verification strongly suggest that high-resolution RAMS forecasts have much greater skill in predicting the development and movement of sea breezes compared to current national-scale weather models.

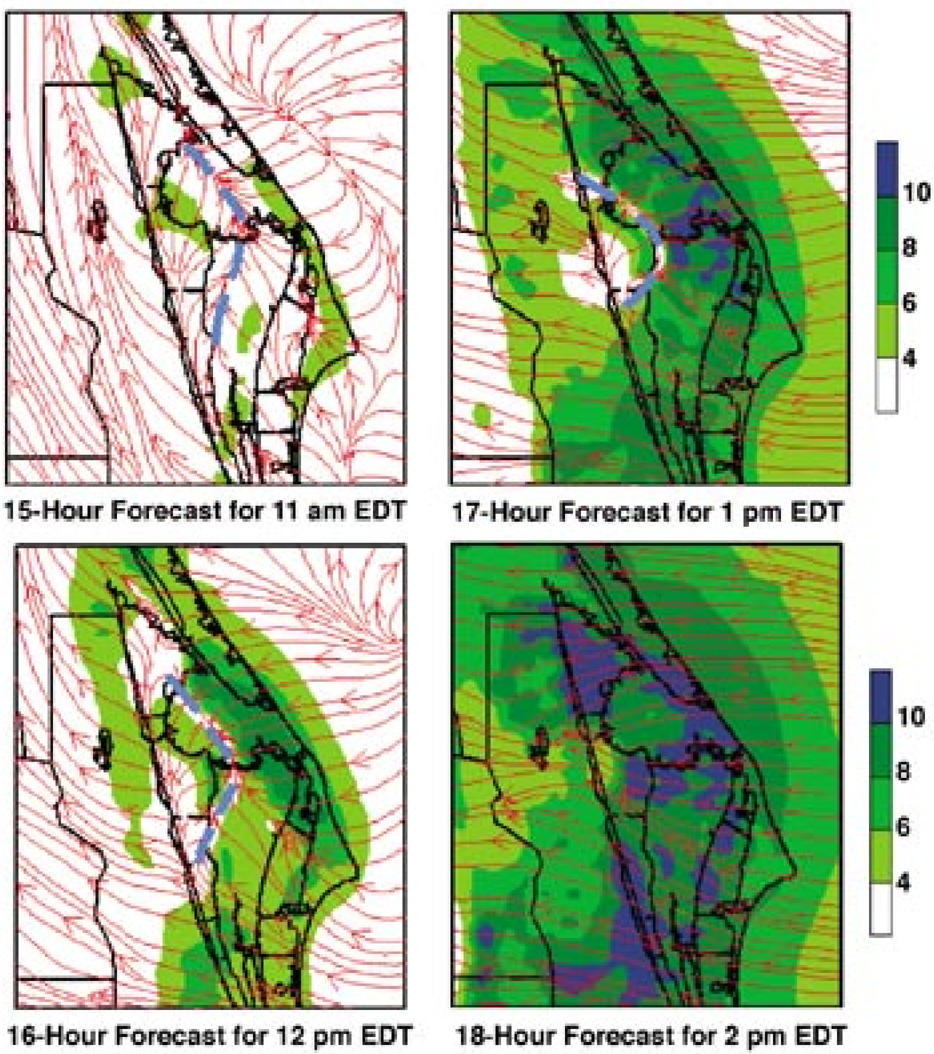

Figure 2. A Plot of the RAMS Forecast Surface Wind Field on 18 August 2000, Illustrating the Interaction Between Local River and Sea Breezes

Key accomplishments:

- 1999: Developed a graphical user interface used to verify RAMS forecasts against national and local observational sensors in real time.
- 1999 and 2000: Performed an evaluation of RAMS for both the 1999 and 2000 Florida warm seasons and for the 1999/2000 Florida cool season.

Key milestones:

- 2001: Final model evaluation results and recommendations for improved visualization and forecast guidance using high-resolution RAMS forecasts.

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Participating Organization: ENSCO, Inc. (J.L. Case)

Command, Control, and Monitoring Technologies

Highly integrated command, control, and monitoring systems will be needed in the future for order-of-magnitude reductions in the labor required to command, control, and monitor second- and third-generation space transportation systems. In the future, labor-intensive subsystem control and monitoring from firing rooms and mission control rooms must give way to operations concepts similar to air traffic control towers. Technologies that allow more ground functions to be accomplished by onboard systems will be needed (more autonomous). This will require new architectures with advanced sensors and instrumentation technologies. The overall architectures will seamlessly integrate ground and flight functions with highly reliable and dependable parts and far fewer of them. The advanced systems will be characterized by far less power and thermal demand, will need far fewer cables and wires, and will provide greater insight into critical systems while maintaining system integrity.

Focus areas include the following:

- Highly Autonomous Command and Control Systems
- System Health Management (ground and flight)
- Sensors and Instrumentation

The goals and objectives of Command, Control, and Monitoring (CCM) include the following:

- Reduce contribution of CCM systems to the cost per pound of payload to orbit
- Increase safety by increased insight into and monitoring of critical systems (sensing) and CCM system reliability (need top-level metrics)

For more information regarding Command, Control, and Monitoring Technologies, please contact Cary Peaden, (321) 867-9296, *Cary.Peaden-1@ksc.nasa.gov*; Carey McCleskey, (321) 867-6370, *Carey.McCleskey-1@ksc.nasa.gov;* or George Hurt, (321) 861-7271, *George.Hurt-1@ksc.nasa.gov*.

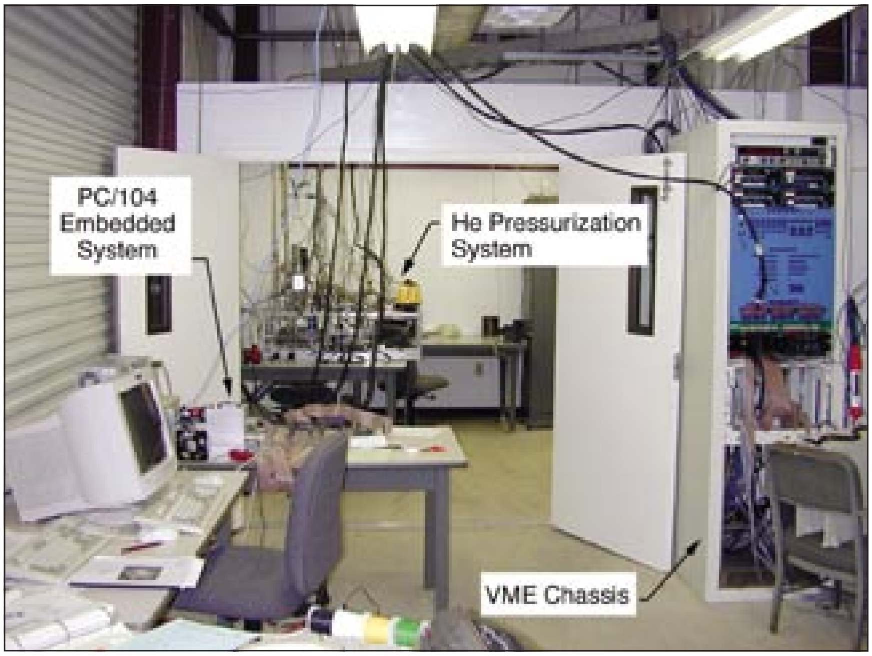
Predictive Health and Reliability Management (PHARM)

Operational costs associated with Space Shuttle component failures, repairs, and/or replacement processes are expensive. To help reduce cost, a PHARM system (formerly known as Demand Management System) is being developed to identify components trending toward failure and thus mitigate impacts to operational testing and mission performance, as well as provide key quantitative information required for proactive repair, replacement, and logistical decisions. An Orbital Maneuvering Subsystem (OMS) Vehicle Health Management (VHM) testbed that performs a complete automated checkout of a simulated OMS helium pressurization system was developed (see the figure). The test article uses qualification hardware in flight configuration. In the course of the automated checkout, key data necessary to predict future component performance is saved, correlated, and used to develop, prove, and demonstrate PHARM technologies.

This year PHARM had three primary tasks: enhance the Spacecraft Telemetry Analysis Tool (STAT), develop an application to automate PHARM prognostics, and develop a Web-based system that interfaces with multiple databases to acquire and disseminate relevant data associated with the unplanned repair process. These capabilities are essential parts of an overall Informed Maintenance (IM) system.

The first task was to implement the user-requested STAT enhancements, which include an enhanced data filter interface, the ability to save and load data sets, and simplified chart and graph printing. The second task leveraged off the Vehicle Health Management development of an inflight checkout of the OMS helium pressurization system to process the test result data produced by the passive health-monitoring node. This node monitors the system state and collects key data necessary to predict system/component health. The new application, the Performance Evaluation Module (PEM), will process the inflight test data and generate reports that predict possible future failures and identify limit violations and out-of-character performances. The last PHARM task was to design and implement a Web-based tool, the Informed Maintenance Information Management (IM^2) system used to acquire and disseminate engineering data from multiple databases, including the Problem Resolution and Tracking System (PRTS) and the Virtual Problem Resolution Team (VPRT) Web sites in support of the unplanned maintenance process.

PHARM demonstrated three basic concepts that are the building blocks for an IM system. These systems (STAT, PEM, and IM^2) mitigate impacts to ground processing and the unplanned maintenance process. STAT proved to be a valuable tool for systems engineering during critical operations such as launch. With the enhancements made to STAT, engineering can now retrieve and analyze high-speed telemetry data (100 hertz). STAT's new data filtering interface enables engineering to have greater control over the scope of the acquired data sets, thereby enhancing the overall productivity of the query process. These new capabilities assist in the early detection of problems and anomalies. Corrective action can be



VHM OMS Helium Testbed

scheduled into the planned maintenance process flow, thus essentially turning unplanned maintenance into planned maintenance.

The PEM application was specifically designed to analyze large quantities of data from the inflight checkout systems and to provide a summary report that identifies components trending toward failure, redline limit violation, and Statistical Process Control (SPC) violation or out-of-family operations. Forecasting potential failures will turn unplanned maintenance into planned maintenance. With the understanding of a system's/component's performance and not just a pass/fail criterion, engineering can use the PEM reports and analysis techniques as a decision tool to defer corrective action until a more opportune time, such as an Orbiter's maintenance downtime. An SPC violation gives engineering advance insight into the system's/component's out-of-family operating characteristics. In statistical terms, this identifies the process as potentially being out of control. Engineering can use this information to proactively address the condition. The PEM application can also be used to support unplanned maintenance processes by providing performance data in support of problem resolution.

The IM^2 system provides engineering with a tool to access multiple data management systems and to acquire and disseminate data via the Web for expediting maintenance decisions and processes. The greatest impacts to launch processing are unplanned maintenance processes. The primary function of the PRTS and VPRT is to support the unplanned maintenance process. The PRTS provides not only problem tracking but also a centralized location where all relevant data associated with a particular problem can be stored. Combining the PRTS and the VPRT enables engineering to support near-real-time problem resolution from multiple locations.

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Participating Organization: Boeing – Florida Space Shuttle Operations (J.M. Engle and W.C. Atkinson)

Liquid Oxygen Sensor

The objective of this project is to design a liquid oxygen (LOX) sensor capable of measuring the amount of LOX with better than 1-percent accuracy. The need to quantify the amount of LOX inside a container or a pipe is well established. The space program requires the capability of monitoring LOX for use on liquid air packs, LOX flow lines, and LOX transfer lines. In addition, interplanetary flights will require the transfer, storage, and handling of vast amounts of liquid oxygen. It is important to be able to measure the amount of LOX remaining in a container.

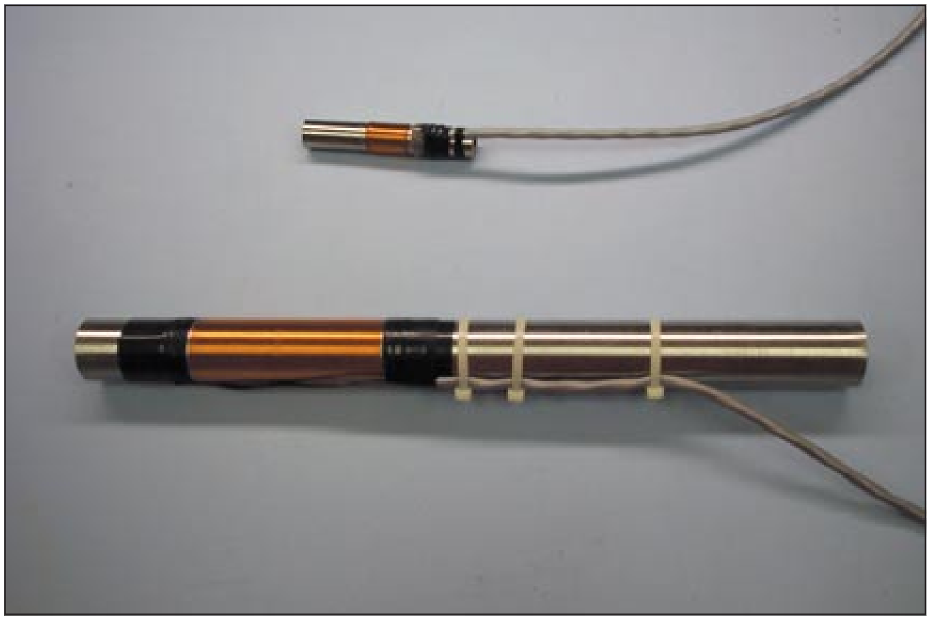
Liquid oxygen exhibits paramagnetic properties. When the intensity of the magnetic field inside a substance is greater than the field applied in vacuum, the substance is called paramagnetic, and the phenomenon of attraction of the substance toward regions of high magnetic intensity is observed. The paramagnetic susceptibility is independent of the magnetic field, although it can typically vary with temperature. Over the years, several methods to measure magnetic susceptibility were devised and tested using uniform and nonuniform field methods. However, classic methods are not directly applicable for measurements of the relatively small paramagnetic properties of LOX in an environment such as that encountered by the aerospace community.

Using low-frequency magnetic fields, the paramagnetic properties of LOX flowing inside a steel pipe can be measured with relatively small errors introduced from the attenuation in the electrically conductive pipe. This nonintrusive measurement can be demonstrated without disturbing the flow of liquid oxygen. For instance, the inductance of a coil wrapped around a steel pipe changes when the pipe is filled with liquid oxygen. The skin depth of the pipe affects the amount of magnetic field in the LOX; consequently, the change in inductance caused by the presence of LOX is dependent on the skin depth. Since the skin depth is a function of the conductivity of the material (stainless steel for this project) and a function of frequency, a direct reading of the inductance alone is not sufficient to characterize the amount of liquid oxygen within a pipe. Another variable is introduced because the conductivity of the material is a function of temperature.

Several elements critical to the successful completion of a field-deployable sensor had to be considered in the design. Among the concerns were:

- Temperature-induced drift had to be eliminated or at least reduced sufficiently to allow for enough sensitivity, resolution, and accuracy in the measurements.
- The effects of eddy currents and the attenuation caused by the skin effect had to be better understood to be able to compensate for them.
- The sensitivity of the sensor to other phenomena (such as the presence of magnetic materials and electronic circuitry inaccuracies) had to be characterized.

The next-generation LOX sensor will actively remove the effects of



Liquid Oxygen Sensor

temperature drifts. To date, the sensor has demonstrated a sensitivity of about 10-percent LOX fill by volume, and significant improvements are expected with better signal processing in the next-generation prototype.

Key accomplishments:

- Developed and tested a prototype sensor.
- Modeled the circuitry to understand the effects of eddy currents.
- Developed an algorithm for real-time temperature compensation.

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Participating Organization: Dynacs Inc. (Dr. P.J. Medelius, J.S. Moerk, and Dr. C.D. Immer)

Hydrogen Fire Detector

The Space Shuttle uses a combination of hydrogen and oxygen as fuel for its main engines. Liquid hydrogen is pumped to the Space Shuttle external tank from a storage tank located several hundred feet away. Any hydrogen leak could potentially result in a hydrogen fire, which is invisible to the human eye. It is important to detect the presence of a small hydrogen fire in order to prevent a major accident. Existing fire detectors, based on the detection of infrared (IR) radiation alone, are very sensitive to other sources of radiation, often misinterpreting them as fires and producing false alarms. The objective of this project is to develop a device that is capable of detecting small hydrogen fires and insensitive to nonflame radiation sources.

A problem with the IR detection circuits found in typical commercial detectors is they operate in the irradiance band from carbon dioxide, a byproduct of hydrocarbon flames. These units employ a flicker detection circuit, which is intended to avoid false alarms caused by hot objects and solar reflection. However, this circuit is sensitive to changing reflections such as the flame from a flare stack or changing shadows from personnel or animal movements nearby. This sensitivity results in false alarms. An advantage of combining ultraviolet (UV) and IR detection is the reduction of false alarms caused by nonflame sources that emit UV radiation only (such as lightning and welding arcs).

A reliable hydrogen fire detector, based on the simultaneous monitoring of UV and IR radiation at two different wavelengths, was developed at KSC. During the research phase of the project, measurements of UV and IR radiation were taken using small hydrogen flames and the large flare stack in the background. Based on the results of these measurements, custom digital signal processing algorithms were devised to determine whether the radiation was from a hydrogen fire or an extraneous source. These algorithms prevent the occurrence of false alarms while maintaining the required sensitivity for the fire detection.

The sensitivity required for proper operation of the sensor at different distances can vary by several orders of magnitude. In the first prototype, the sensors were configured for manual adjustment of the gain in their front-end stages. This resulted in sensors being disassembled and then reassembled every time sensitivity changes were required. The latest version of the sensor now incorporates electronic gain control for adjusting the sensitivity of the amplifiers, either under control of a host computer or from its own embedded digital signal processor.

Real-time digital filtering and cross correlation are used to determine the presence of a fire within the detector's field of view, while discriminating from radiation from manmade sources or solar reflections. The resulting sensor can detect the presence of a small hydrogen flame, even when reflections from the large flare stack are received. Several of these detectors have been prototyped and are currently being tested at the Space Shuttle launch pads.

Hydrogen Fire Detector

The algorithms developed for the hydrogen fire sensor greatly enhance the current technology by allowing a smart decision to be made regarding the presence of a fire. The detector unit was designed to incorporate all the components needed for fire detection in a single enclosure, including UV and IR detectors, lenses, amplifiers, converters, and a digital signal processing unit. The unit is capable of interfacing with a computer to allow changes in the cross-correlation thresholds. Variants of the algorithm can easily be downloaded to the sensing unit for field-testing and fine-tuning purposes.

Key accomplishments:

- Designed and built five prototype sensors.
- Conducted laboratory testing of sensors.

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Participating Organization: Dynacs Inc. (Dr. P.J. Medelius, J.D. Taylor, J.A. Rees, and J.J. Henderson)

Advanced Power Supply Development

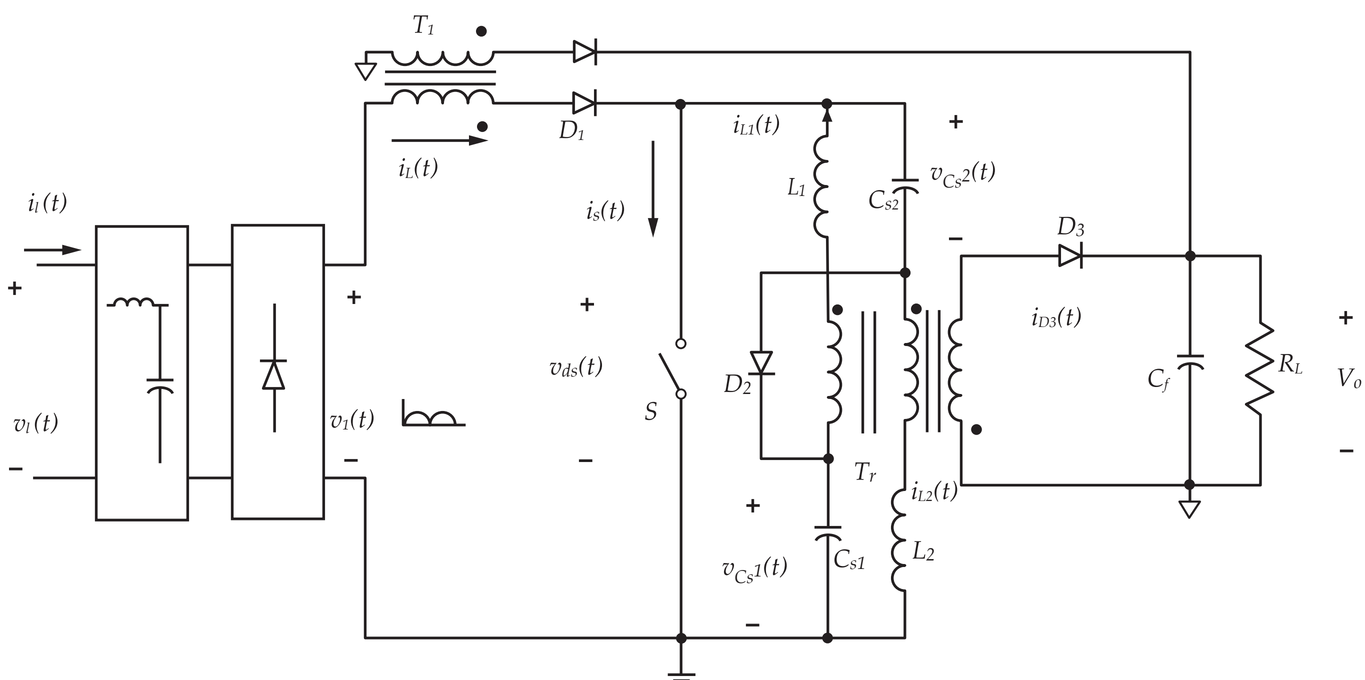
Kennedy Space Center has partnered with the University of Central Florida and Electrodynamics Associates, Inc. to develop an advanced power supply prototype. This project targets declining power quality in Shuttle ground data processing centers and thereby improves power system performance.

The quality of electrical power was never more critical to NASA than it is today. This is because of not only the widespread use of sensitive electronic equipment but also the increased dependency on this equipment's continuous and troublefree operation. The most significant threat to power quality comes from the nonlinear power supplies used in virtually every piece of data processing hardware at KSC. These power supplies inject large amounts of current harmonic distortion throughout the power distribution system. High harmonic distortion commonly causes erratic equipment operation and in some cases results in fire and/or electrical shock hazards. This type of equipment at KSC is rapidly increasing, and the total harmonic distortion on the power system is on the rise. As a direct result, power quality surveys reveal high levels of harmonic distortion in many Shuttle program main data processing centers.

As current harmonics increase the root mean square (RMS) value of the current waveform, they do not deliver any real power in watts to the load. As a result, new system designs must account for higher harmonic distortion levels by the use of larger distribution hardware (K-factor-rated transformers, larger conductors, larger breakers, etc.).

The use of this advanced power converter eliminates the additional stresses on the power distribution system caused by harmonic distortion. As a result, new power distribution designs will not require derating for harmonic loads and will therefore save on overall project costs. Further, in existing power distribution systems, this technology can significantly reduce the load on the electrical system. Harmonic currents account for a full third of the RMS current in some Shuttle processing centers.

A new prototype was developed to meet the target specifications. The circuit topology provides for a unique blend of efficiency, reliability, and energy density. The proposed circuit topology is a single-stage processor and is therefore more efficient than the two-stage topologies available. Furthermore, since the topology uses a single solid-state switch, reliability is increased. Finally, since the unit utilizes the circuit's parasitic elements rather than employing additional discrete components, energy density is improved.



Schematic Diagram of Advanced Power Supply

The new topology combines one flyback converter and one forward converter using only one switch and one control circuit. The main advantages of the new topology include:

- Higher efficiency, since part of the input energy is transferred directly to the load
- A smaller output filter capacitor, since the capacitor current is composed of two components with cancellation
- Use of low-voltage components, since the direct current (dc) bus voltage is limited by the flyback converter

A 150-watt, 28-volt (V) dc output hard-switching prototype was constructed. Its efficiency ranges from 80 to 85 percent under universal input voltage (85 to 260 V ac), and the power factor exceeds 0.975 under all conditions. Commercial packaging and control design are expected to produce further improvement.

This KSC-sponsored effort promises to bring technology that previously had been solely the subject of research in the commercial market. As a result, the new design has the potential to be better than any commercially available design and be reduced in cost.

Key accomplishments:

- 1999: Shuttle Technology Transfer Research (STTR) Phase I – Feasibility Study and Circuit Topology Evaluation
  - Selected target topology for development based on efficiency, energy density, reliability, and simplicity.
  - Developed target specifications by review of commercially available units.
- 2000: STTR Phase II – Simulation and Testbed Development
  - Topology design and modification completed for hard-switching topology.
  - Soft-switching design under evaluation.
- 2001: STTR Phase II – Prototype Development
  - Breadboard prototype constructed and refined.
  - Prototype meets or exceeds all target specifications.
  - Prototype turned over to the power supply company for industry printed circuit board design, layout, and packaging.

Key milestones:

- 2001: STTR Phase II – Commercial Prototype Development
  - Commercial packaging of the prototype, including the addition of standard power supply protection functions and control circuitry.
  - Benchtop testing of the commercial prototype.
  - Field testing at KSC.

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Participating Organizations: University of Central Florida (Dr. I. Batarseh) and Electrodynamics Associates, Inc. (J. Vaidya)

Performance Data 2

Input Voltage	Output Voltage	Input Power	Output Power	Voltage Across Storage Capacitor	Power Factor	Efficiency (%)
85	27.11	175.3	141.7	132	0.996	80.8
115	28.12	184.5	153.2	152	0.978	83.0
130	28.19	183.8	153.9	164	0.990	83.7
150	28.21	183.0	154.2	181	0.991	84.2
175	28.23	182.6	154.4	202	0.989	84.5
200	28.25	183.0	154.6	222	0.989	84.5
225	28.26	183.5	154.7	242	0.988	84.3
250	28.26	184.5	154.7	263	0.986	83.8
275	28.30	186.1	154.6	279	0.984	83.1

Notes:

1. *Switch frequency is 70 kilohertz (kHz).*

2. *Using MPP core as the flyback transformer T_1 core, turn ratio is 33:8.*

3. *Flyback inductor is 96 microhenry (μH), Tr turn ratio is 0.333, and output inductor is 16 μH.*

Smart Current Signature Sensor

The Advanced Sensors Development Laboratory of the NASA Instrumentation Branch was tasked with the development of a solenoid valve current sensor that meets the following requirements:

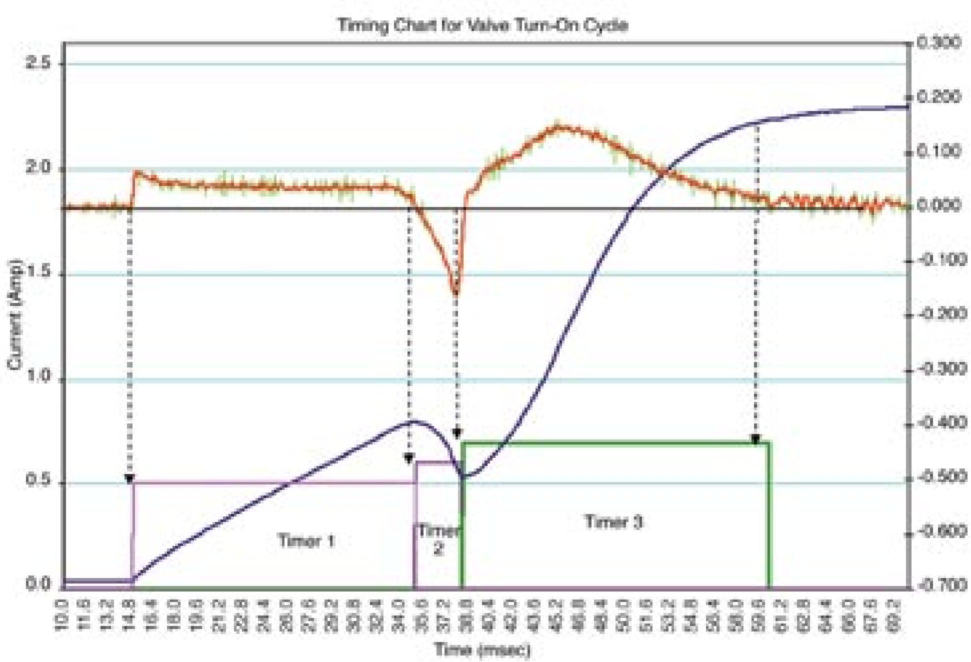
- Monitor the desired parameter without interfering with Orbiter systems (be noninvasive)
- Monitor the parameter and predict the performance and health of the device. Ultimately, predict a failure before it happens

Commonly, the parameters monitored in a solenoid valve are voltage and current. Since the current sensor has to be noninvasive, the magnetic field generated by the solenoid current was selected as the parameter to be monitored.

The design presented here monitors the solenoid valve's electrical current for health status and prediction. Both the steady-state and the turn-on and turn-off transitions of the current signal are monitored. The on/off transitions contain characteristic peaks and valleys that repeat every cycle. The peaks and valleys are like a signature with defined times, current magnitude, and shape. As electrical and/or mechanical degradation occurs in the solenoid valve, the signature changes both in time and magnitude, thus becoming a clear indicator of potential problems.

The sensor is composed of a signal acquisition assembly and a signal conditioner and controller assembly. The signal acquisition assembly contains the magnetic and temperature sensors. It also contains the magnetic flux concentrator as well as a shielding cage for the magnetic sensor. The magnetic sensor selected is a linear Hall Effect sensor. The output voltage is linearly proportional to the surrounding magnetic field. To maximize the magnetic field (flux) in the Hall Effect sensing area, a flux concentrator is used. To prevent external magnetic field interference, a magnetic shielding cage is built around the sensor. One of the major obstacles encountered when using Hall Effect sensors is their dependence on the environment's temperature. As temperature changes, drifts in the offset voltage and sensitivity of the sensor can be observed. Furthermore, the measured drifts, although predictable for each sensor, change from sensor to sensor. This design approaches this problem in a unique way. The design presented here is able to compensate in real time for these parameter variations.

The signal conditioner/controller assembly will provide the following functions: (a) amplification of the low-level signal from the signal acquisition assembly to a manageable level, (b) continuous real-time temperature compensation of sensor offset and sensitivity (gain) drift, (c) real-time in-circuit calibration of the current signature sensor, (d) real-time current signature analysis and trend analysis, and (e) alert/annunciation if functional degradation of the valve occurs or a failure exists in the valve.



Solenoid Valve Electrical Current Turn-On Transition

Valve health analysis and failure prediction will be performed using software algorithms residing in the microprocessor controller module. Information on the characteristics (signatures) of the current signal will be extracted from the analog signal and compared with stored parameters of a typical solenoid behavior for that species of valve. The comparisons performed will be graded as nominal, borderline, or failure. An account of these results will be stored and forwarded to the user for further action.

A simple algorithm was devised to detect specific characteristics in the current signal. A derivative like real-time calculation applied to the time-domain signal allows the peaks and valleys of the current signal to be detected and time-tagged by looking for the signal transitions from positive to negative and vice versa (zero-crossing transitions). Signal slope and steady-state values are also monitored to complete the characterization of the current signature.

Key accomplishment:

- Continuous real-time compensation of offset and sensitivity (gain) drifts over a wide temperature variation.

Key milestones:

- Perform a real-time current signature analysis and trend analysis (2001).
- Develop the capability for real-time calibration of the current signature sensor (2001).
- Develop a valve signature database and the capability to inform the user if functional degradation or failure of the valve has occurred (2002).

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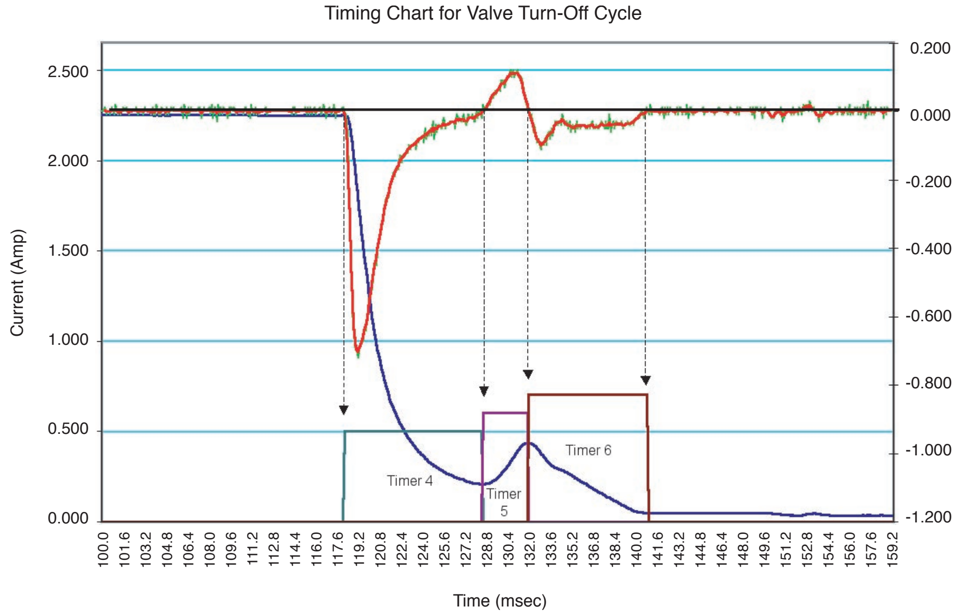
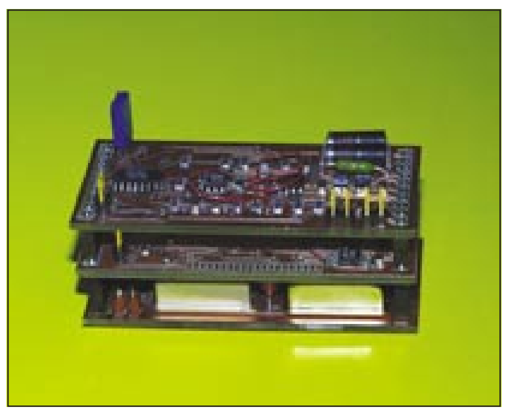
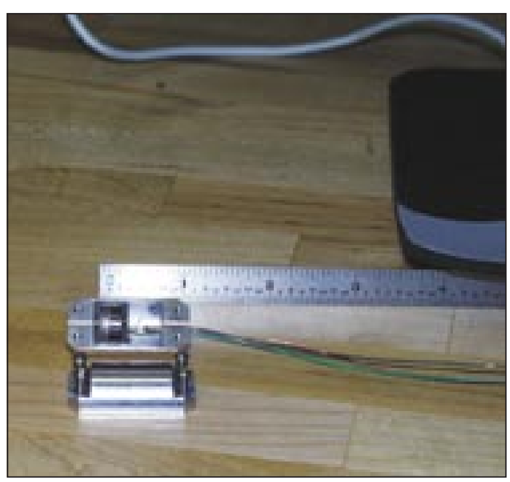
Participating Organization: Dynacs Inc. (B.M. Burns)



Solenoid Valve Electrical Current Turn-Off Transition



Signal Conditioner and Controller Assembly Prototype



Sensor Acquisition Assembly Prototype

Multisensor Array – Are More Sensors Better Than One?

Common sense seems to suggest that multiple sensors are better than one and, if so, how much better? The goal of this project is to design and implement a test to answer this question and to help quantify the relationship between the number of sensors and the associated improvement in sensor life and reliability.

Multiple sensors can be implemented in numerous ways, the most direct of which is to simply increase the number of sensors of a particular type at the measurement site. Another method, which takes advantage of the reduced size of microelectronic sensors, is to pack several sensors onto a single circuit board. Going one level smaller, multiple integrated circuit (IC) sensors composed of single die (small rectangles of silicon containing the transducer circuitry) can be crammed into a single IC package. Finally, multiple sensors can be fabricated directly onto a single die using advanced technologies such as microelectromechanical systems (MEMS). Whatever the technique used to implement a multisensor array (MSA), the question still remains: "Is it better and, if so, how much better?"

A first step at answering this question is to create a type of computer experiment, referred to as a Monte Carlo simulation. An array (or cluster) of *N* sensors undergoes random failures, such that the statistical mean of the failure mode remains constant (zero mean drift). A life extension factor (LEF) is defined as a percentage of the life of a single sensor. When the LEF is plotted as a function of *N* (the number of sensors of the array), a maximum LEF of 3 is reached beyond *N* > 30, as shown in figure 1.

The next step following the computer experiment is a test using real devices. For this, an array was chosen of pressure sensors attached to a single circuit board, approximately 1-inch square, and containing eight 8-lead circuit-mount packages. To

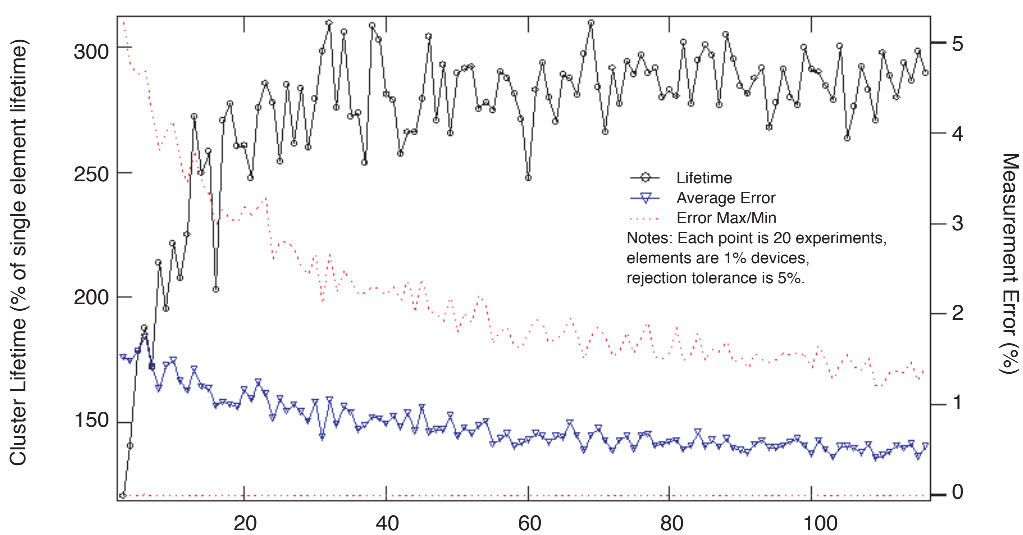


Figure 1. Monte Carlo Simulation of Multisensor Array

accelerate sensor failures, the environment temperature is raised to 125 degrees Celsius (°C). Every 24 hours, all sensors are returned to an ambient temperature of 27 °C and measured at ambient pressure. Once a week, a pressure calibration is made of all eight sensors at five pressures: 3, 6, 9, 12, and 15 pounds per square inch absolute (psia). The test continues until all but two sensors have failed or until the elapsed test time exceeds 1000 hours. Figure 2 shows the pressure vessel containing the MSA under test, which sits in the temperature chamber.

Using the initial pressure calibration, the MSA under test is processed with a multisensor array algorithm (MSAA) and compared to the measurement error of each individual sensor. This is identical to the processing used in the Monte Carlo simulation. Other algorithms may be tested and evaluated as well.

When more than one test temperature is used (more than one test group), an Arrhenius model analysis can be performed. Using data from each of several groups, an activation energy can be extracted using the Arrhenius equation. Using standard statistical methods, a calibration error distribution (which is a function of time and temperature) will be estimated. The drift of the mean and variance of this distribution will be determined (drift of mean corresponds to systematic failure modes; increase in variance corresponds to random failure modes).

Key accomplishments:

- Developed and tested a Monte Carlo simulation to quantify the relationship between the sensor life (length of time between maintenance calibrations) and the number of sensor array elements under the assumed constraint of zero mean output drift.
- Designed and implemented a test to measure the relative LEF of multisensor arrays using a single accelerated life test.
- Specified a test to estimate the absolute LEF of a multisensor array of a specific sensor model and type using multiple accelerated temperatures.

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Participating Organization: Dynacs Inc. (A.J. Eckhoff, Dr. C.D. Immer, and Dr. J.E. Lane)

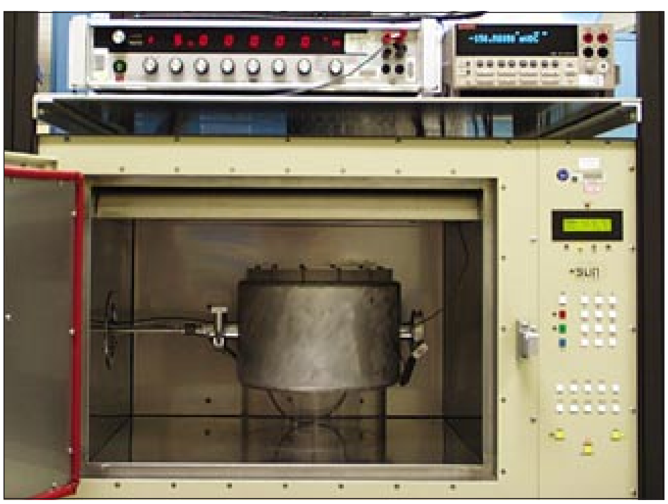


Figure 2. Temperature and Pressure Chambers for Testing MSA

Model for Estimating Absolute Lifetime

$$\lambda = \lambda_0 \, e^{-Q/T + \sum_i \alpha_i S_i}$$

λ *Degradation Rate*

Q *Activation Energy* (of failure mechanism)

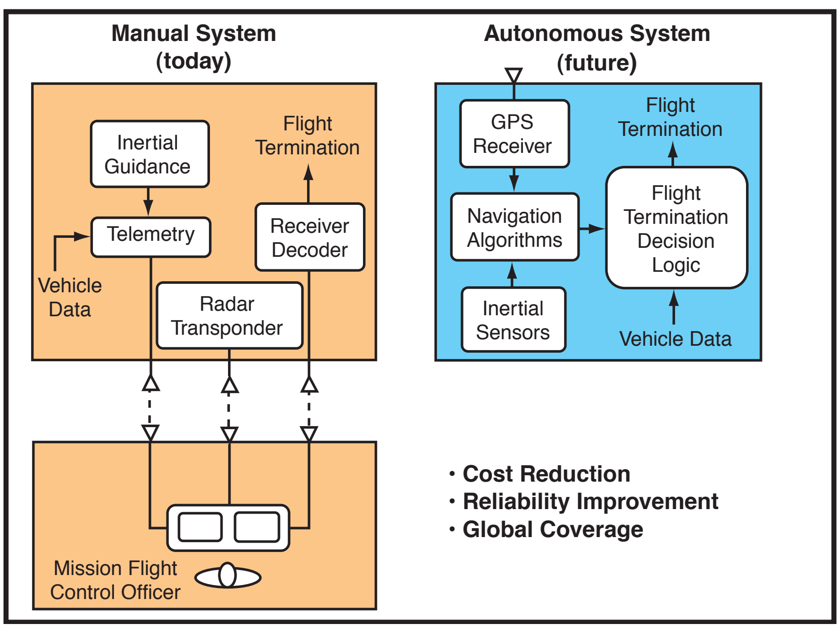
T *Absolute Temperature*

S_i i^{th} *Environmental Stress Factor*

λ_0, α_i, Q *Model Parameters* (curve fitting parameters)

Autonomous Flight Safety System (AFSS)

It costs about $700,000 to operate the range tracking and telemetry equipment during a typical rocket launch (Delta 2 class). NASA is looking for ways to reduce these operational costs for future launch systems. The AFSS concept offers an autonomous vehicle capability that could dramatically reduce these costs by eliminating the range safety "red button" on the ground and, thereby, reduce the people, displays, computers, radar, and radio frequency (RF) links associated with the operation of that button. Can such an autonomous system meet the rigorous reliability requirements and be economical? Can it adequately replace the human in the loop? The objective of the AFSS project is to answer these questions by developing and thoroughly evaluating a prototype system, first by ground testing and later by flight testing as an advisory system.

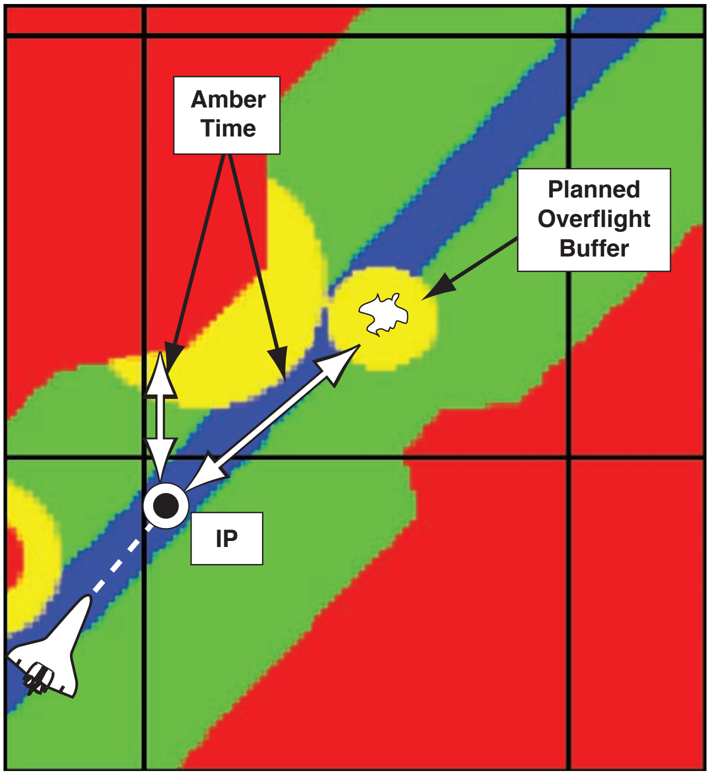


The AFSS technical approach is to devise onboard software logic that emulates the human decision process. The logic would use state vector data derived independently from dual-phenomena measurements [global positioning system (GPS) and inertial navigation system (INS)] on the vehicle. Data from multiple GPS/INS units provide a reliable capability to track the vehicle's position, velocity, attitude, and angular rates during safety-critical flight phases. Multiple AFSS processors would host the decision logic software, and two deadman switches would be configured to provide fail-safe redundancy.

Using flight path deviation allowances and range safety limit zones stored in the AFSS processors, the software is able to accurately assess current vehicle "state vector" and make future flight predictions so appropriate decisions can be made regarding flight continuation, an intact abort, or termination. The software would also ensure valid data is being used to determine the flight behavior and manage the response to AFSS failure modes. The deadman switch logic, implemented by hardware, would automatically initiate the appropriate termination or abort action if the AFSS "goes brain dead" (i.e., data is lost or becomes totally ambiguous for a predetermined time period).

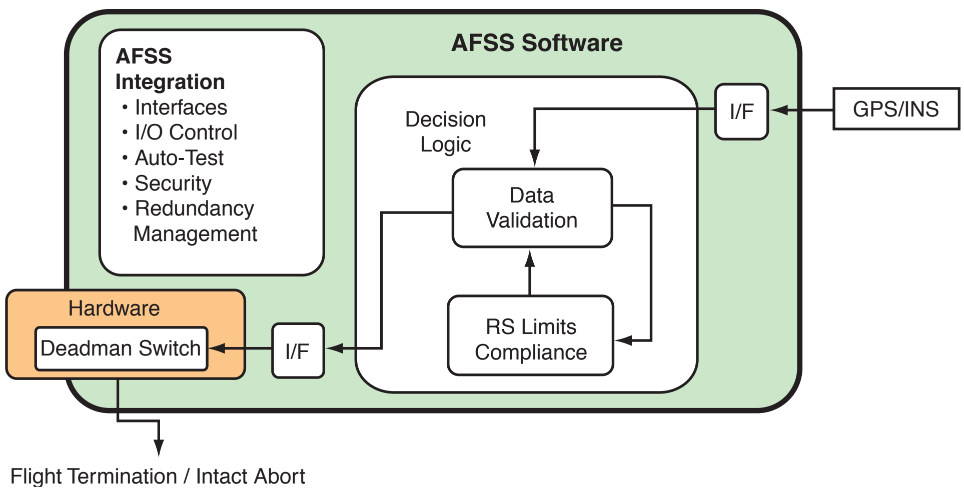
Key accomplishments:

- Requirements, preliminary design, and decision logic simulation on a desktop work station.



Example Decision Logic Algorithms

- *IP Location: The AFSS advises or initiates flight termination or abort if the predicted Impact Point (IP) penetrates any red zone.*
- *IP Ground Speed: The AFSS advises or initiates flight termination or abort if the ground speed is below a predetermined limit while in the yellow (planned overflight) buffer zone.*
- *Amber Time: In the event the AFSS data is lost or becomes totally ambiguous, a timer in the deadman switch delays any irreversible action regarding flight termination or abort for a safe time period based on time-to-endangerment calculation. This protects against any temporary glitches and provides time to gather data before termination is executed.*



Key milestones:

- 2002: Evaluation of a single-string and multistring AFSS breadboard in the George C. Marshall Space Flight Center (MSFC) Simulation Laboratory. Design of a high-fidelity AFSS flight test article.
- 2003: Evaluation of an AFSS flight test article via a ground test in the MSFC Simulation Laboratory.
- 2004: Evaluation of an AFSS flight test article via a flight test on a to-be-determined aircraft.
- 2005: Evaluation of an AFSS flight test article via a flight test on a to-be-determined X-vehicle.

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Participating Organizations: MSFC (K. Schrock and L. Brandon) and Lockheed Martin Space Systems Co. – Astronautics (S. Haley)

Infinite Impulse Response Filters for Postprocessing Noisy Field Test Data

Acquiring field test data can be a challenging task, and preparation for such an event is often filled with last-minute test plan changes. One of the paramount decisions a field experimenter must make is what strategy to use for filtering field data. On one hand, a good strategy is to prefilter the data before acquisition so the collected data has an improved signal-to-noise ratio (SNR). An opposing strategy is to collect raw data, including noise, then filter the data back in the laboratory. The latter strategy has a great advantage in that it may remove some of the burden from the experimenter in preparing and executing the field test, since collecting raw, unfiltered data is generally a much easier task.

Figure 1 is a scatter plot of noisy pressure data acquired from a wind tunnel test of an experimental NASA hurricane wind sensor that measures orthogonal components of wind. The vertical axis of the plot is unprocessed sensor data, while the horizontal axis represents reference pressure data from a pitot tube. In this application, the North-South (NS) axis is aligned to the free stream of the wind tunnel. The East-West (EW) axis is transverse to the flow. Since there is a slight dependency of the EW axis with wind tunnel speed as indicated by the pitot tube pressure (P_d), it suggests that the orthogonal flow sensor was not precisely aligned in the tunnel. The data is further corrupted by broadband noise, which decreases somewhat with frequency. The data was acquired without prefiltering at a rate of sample frequency (fs) = 1000 hertz (Hz). It is expected that the sensor data versus reference pressure data should follow a straight line or one with some weak power-law dependence. As can be seen in figure 1, noise (broadband in this case) severely corrupts the data. An obvious solution is to postfilter the data.

A first-order digital low-pass filter is constructed by implementing a running average on a stream of sampled data using one previous input and one previous output for each new input sample. Because of the use of a previous output, this type of filter is called a recursive filter or an infinite impulse response (IIR) filter. An impulse response is the characteristic filter output caused by an input composed of a single pulse (1 followed by all 0's). The impulse response is infinite in duration, and the IIR filter can be modeled by the resistor capacitor (RC) circuit. (See figure 2.)

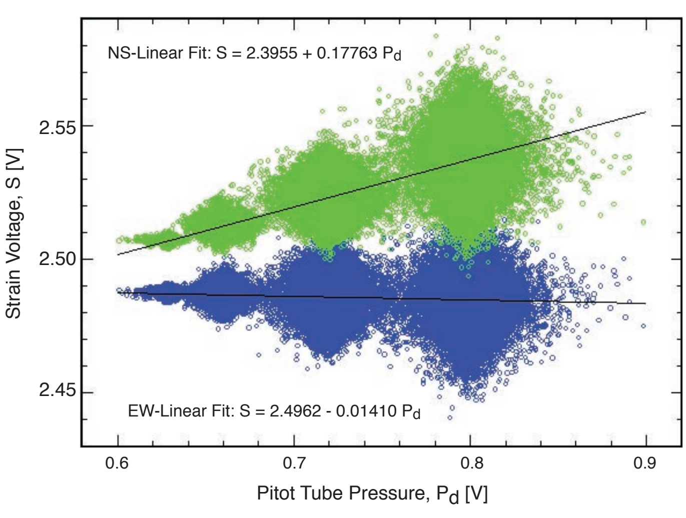

Figure 1. Wind Sensor Strain Gage Voltage Versus Pitot Tube Pressure

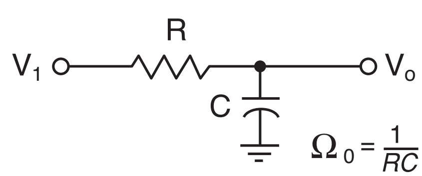

Figure 2. RC Low-Pass Filter Network

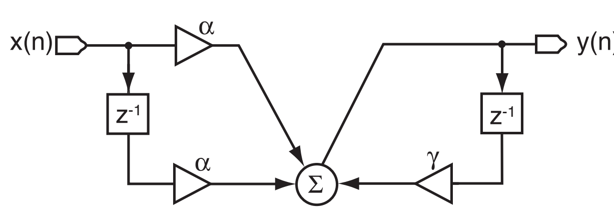

Figure 3. Digital Low-Pass Filter Network

The basic components of the digital filter network, as shown in figure 3, are the multiplier (triangle), adder (circle), and delay element (rectangle). When using a general-purpose programmable digital signal processor (DSP) implementation, these components correspond to key instructions of the DSP's instruction set. Typically in a pure hardware or DSP implementation, the multiplier and adder are combined into a single unit, the accumulator.

In order to implement a digital IIR filter, a difference equation is used. As shown in the table, $x(n)$ is the current input sample; $x(n\text{-}1)$ is the previous input sample; $y(n\text{-}1)$ is the previous output; and $y(n)$ is the new filtered output. The filter coefficients α and γ are also defined in the table. These coefficient formulas result in a tunable IIR filter response, which is inherently stable over the entire digital frequency range, 0 to the Nyquist frequency (one-half of the sample frequency). Even though stability is robust, care must be taken since stability will degrade with decreased numerical precision (number of bits used to represent the coefficients and the filter states).

Key accomplishments:

- Smoothed the noisy wind tunnel test data with first- and second-order recursive averaging, based on tunable IIR filter algorithms.
- Showed that best results were obtained with a first-order filter and a normalized frequency between 0.02π (figure 4) and 0.002π (figure 5).
- The optimized IIR postfilter can be directly replaced by an equivalent RC or resistance capacitor inductor (RCL) prefilter.

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Participating Organization: Dynacs Inc. (Dr. J.E. Lane)

Table 1. 1st Order IIR Low-Pass Filter Formulas

$$y(n) = \alpha[x(n) + x(n\text{-}1)] + \gamma\, y(n\text{-}1)$$

$$\gamma = \frac{\cos\theta_c}{1+\sin\theta_c} \qquad \alpha = (1\text{-}\gamma)/2$$

$$\text{where, } \theta \equiv 2\pi f \,/\, f_s \qquad \theta_c \equiv 2\pi f_c \,/\, f_s$$

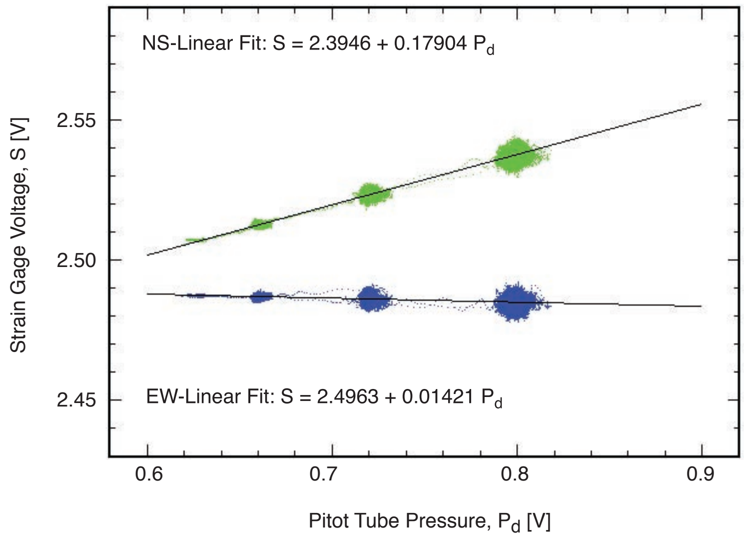

Figure 4. Figure 1 Processed With 1st Order IIR Filter θc=0.02π

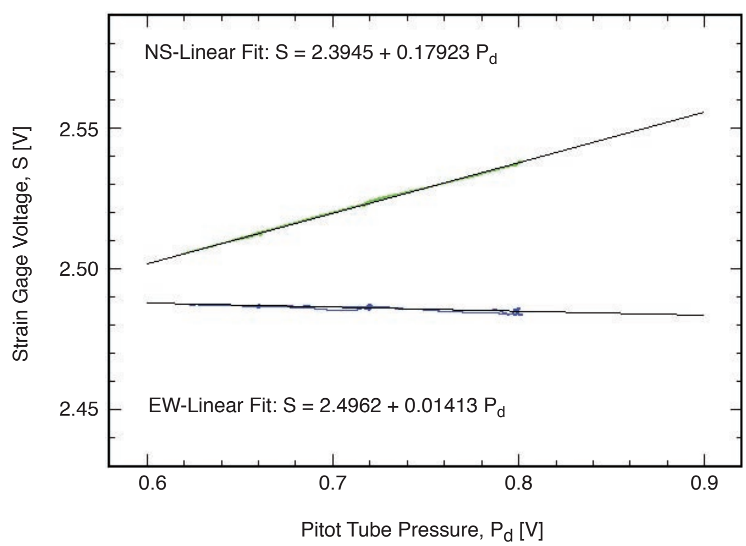

Figure 5. Figure 1 Processed With 1st Order IIR Filter, θc=0.002π

Wireless Sensor Communication

Current and future design goals in the aerospace sensors and transducers field call for the development of new sensing devices that require less electrical power, occupy less space, and weigh less. Self-calibration, self-health assessment, processing of raw data at the sensor level, and alternate data transmission methods are desired to provide the user with information in a more efficient way. The Instrumentation Branch of the NASA Spaceport Engineering and Technology Directorate at Kennedy Space Center, along with Dynacs Inc., was tasked to investigate new ways to design and develop transducers with these characteristics. As part of the initial efforts to acquire the skills and new technologies for such pursuits, the Transducers Development Group began investigating the use of wireless communications at the sensor level.

The group investigated different approaches for wireless communication; the proposal of suitable data transmission methods, depending on different KSC launch operations environments; and the demonstration of initial prototype wireless sensor communication modules. Hopefully, this ongoing effort will result in the design and integration of an advanced data processing and wireless communication system incorporated in the transducer electronics design itself.

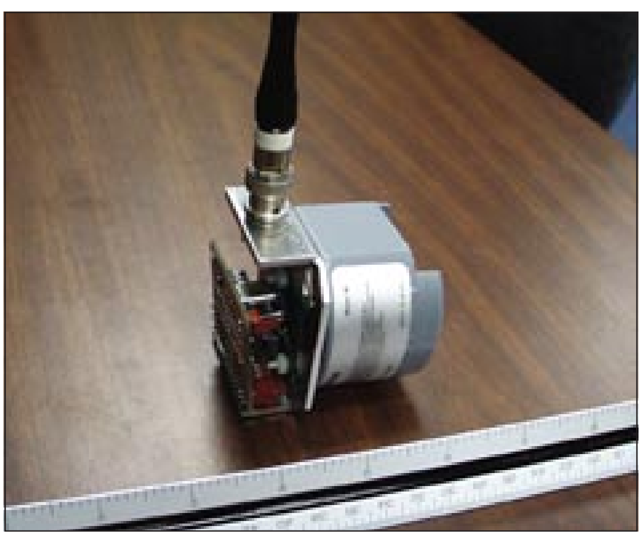

Figure 1. Transceiver Module Electronics With Temperature Signal

From a technology survey that summarized available and emerging wireless hardware and implementation technologies, basic communication schemes and commercially available hardware were selected. Supportive electronics, necessary to operate both the wireless transceiver and the attached sensor, were designed. Custom software was also designed to configure each remote transceiver module and the central data transceiver system and to operate the polling-method communications of the operating system. Commercially available 433-megahertz (MHz) radio transceivers were selected and integrated with power and memory electronics to form small wireless communication modules that attached directly to existing sensors (figure 1). Communication between the central transceiver system and remote transceiver modules was achieved over a distance of approximately 100 meters with only 10 milliwatts (mW) of output power.

Key accomplishments:

Wireless communication modules were successfully developed and demonstrated in a direct-polling system in four different configurations (figure 2):

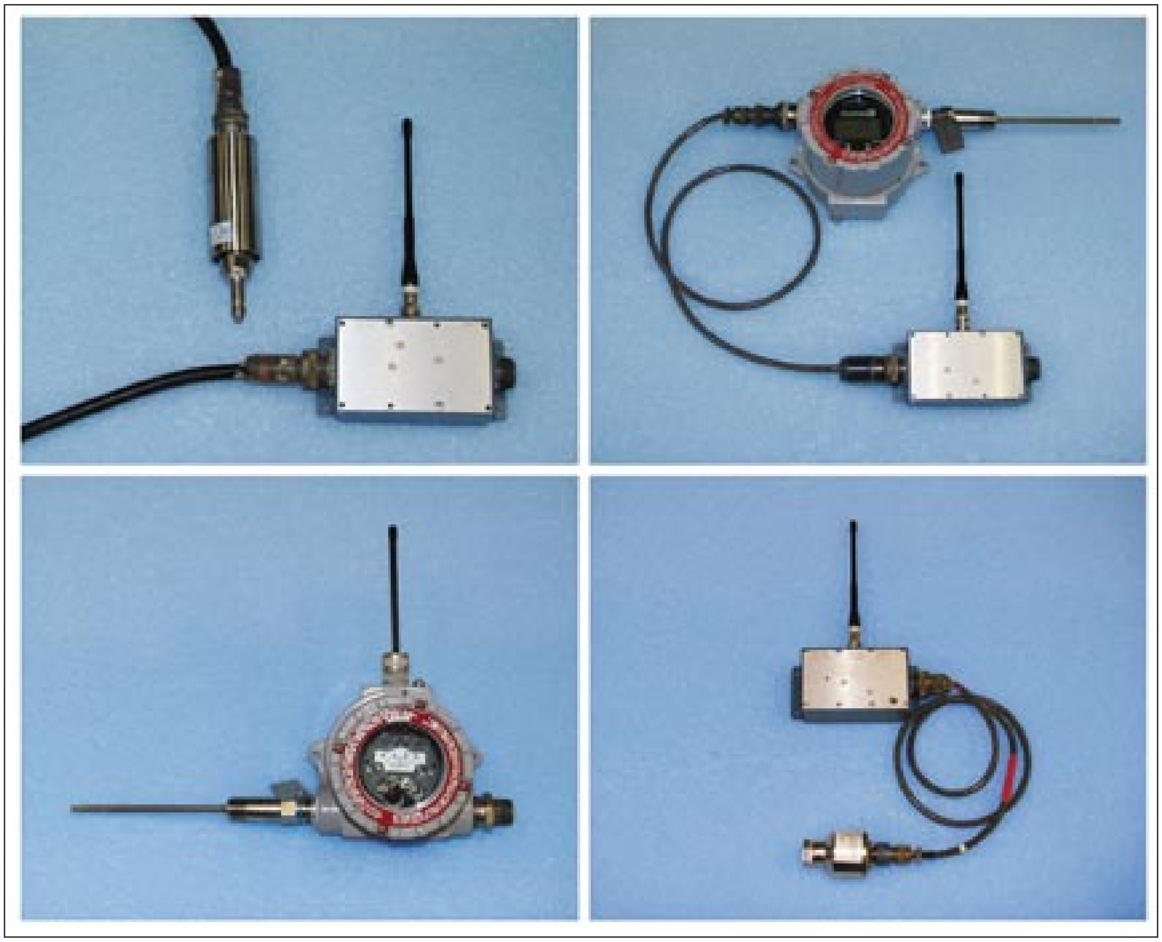

Figure 2. Wireless Communication Sensor and Transceiver Module Configurations

- In-line module that utilizes 28-volt (V) direct current (dc) power, feeds 28 V dc through to the transducer, and accepts a 0- to 5-V dc input from the transducer for conversion to the wireless transmitted data.
- Voltage or current transducer transceiver module that utilizes the external power necessary for the end-item transducer and accepts either a voltage or a current input signal from the transducer for conversion to the wirelessly transmitted data.
- Integrated sensor/transceiver module that contained a wireless communication assembly included with a temperature signal conditioner and enclosed within an explosionproof housing.
- Battery-operated transceiver that utilized 9-V dc batteries to demonstrate a self-contained, battery-powered, wireless sensor data transmitter.

Key milestones:

- 2000/2001:
  - Expand for other communication scenarios to include a local sensor communication network, a long-range transmitter/repeater network, and a multipath/multireceiver network.
  - Improve software for communication error recovery.
  - Develop high-level, in-sensor data processing systems.
  - Investigate system enhancement possibilities using Bluetooth standard wireless products.

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Participating Organization: Dynacs Inc. (M.N. Blalock, A.J. Eckhoff, Dr. J.E. Lane, and Dr. P.J. Medelius)

Evaluation of the Triboelectric Sensors in the Mars Environmental Compatibility Assessment Electrometer

The Mars Environmental Compatibility Assessment (MECA) Electrometer was designed jointly at the Jet Propulsion Laboratory and at the Electromagnetic Physics Laboratory at KSC to be a flight instrument on a future unmanned Mars mission. The MECA Electrometer was designed primarily to characterize the electrostatic properties of insulating materials that would come into contact with the soil of Mars. The materials were selected based on their use in previous space missions. The five insulators chosen for the MECA Electrometer were: fiberglass/epoxy, polycarbonate (known as Lexan™), polytetraflouroethylene (Teflon™), Rulon J™, and polymethylmethacrylate (Lucite™ or PMMA).

The triboelectric sensor array consists of five (6.35-millimeter-diameter) circular patches of the insulating materials placed above metal electrodes. The five individual electrodes are connected to independent electrometer circuits. The five outputs are collected via a serial connection to a controlling computer. The tribosensors are housed inside the MECA Electrometer, whose case is made of titanium of a volume of approximately 50 cubic centimeters and a total mass of approximately 50 grams. The power consumption is less than 250 milliwatts. Figure 1 is a photograph of the MECA Electrometer. Figure 2 is a simplified representation of the circuitry for one tribosensor. Figure 3 shows a typical output in a low-pressure carbon dioxide (CO_2) atmosphere.

The five circular patches shown in figure 1 are the five types of insulators used in this project. The electrometer's circuitry, below the patches, measures the amount of electric charge that develops on the insulator surfaces after the electrometer is dragged through the Martian soil simulant. The two openings shown above the five insulators in figure 1 are the local electric field sensor on the left and the ion gage (IG) on the right. The temperature sensor is a dedicated integrated circuit chip that is mounted inside the case and is not shown in figure 1.

A thorough evaluation of the sensitivity of the tribosensors was performed. It was determined that the gain in the current electrometer circuitry should be programmable to compensate for a variety of surface conditions that might be encountered on Mars.

Figure 1. MECA Electrometer

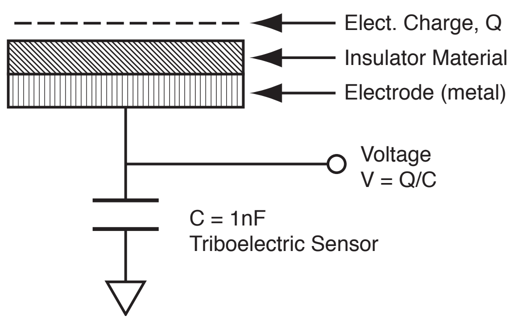

Figure 2. Tribosensor Circuitry

Key accomplishments:

- The triboelectric sensors were tested with Martian soil simulant in dry air and under a low-pressure CO_2 atmosphere.
- The gain of the tribosensors was 0.25 nanocoulomb per volt (nC/V) as measured at the output and found to be too low to measure the maximum charge that can accumulate on the materials.

Key milestone:

- Enhancements to this instrument.

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Participating Organizations: Florida Institute of Technology (Dr. J. Mantovani), Wilkes University (A. Linville), and YA-F2-T (E.E. Groop and Dr. R.H. Gompf)

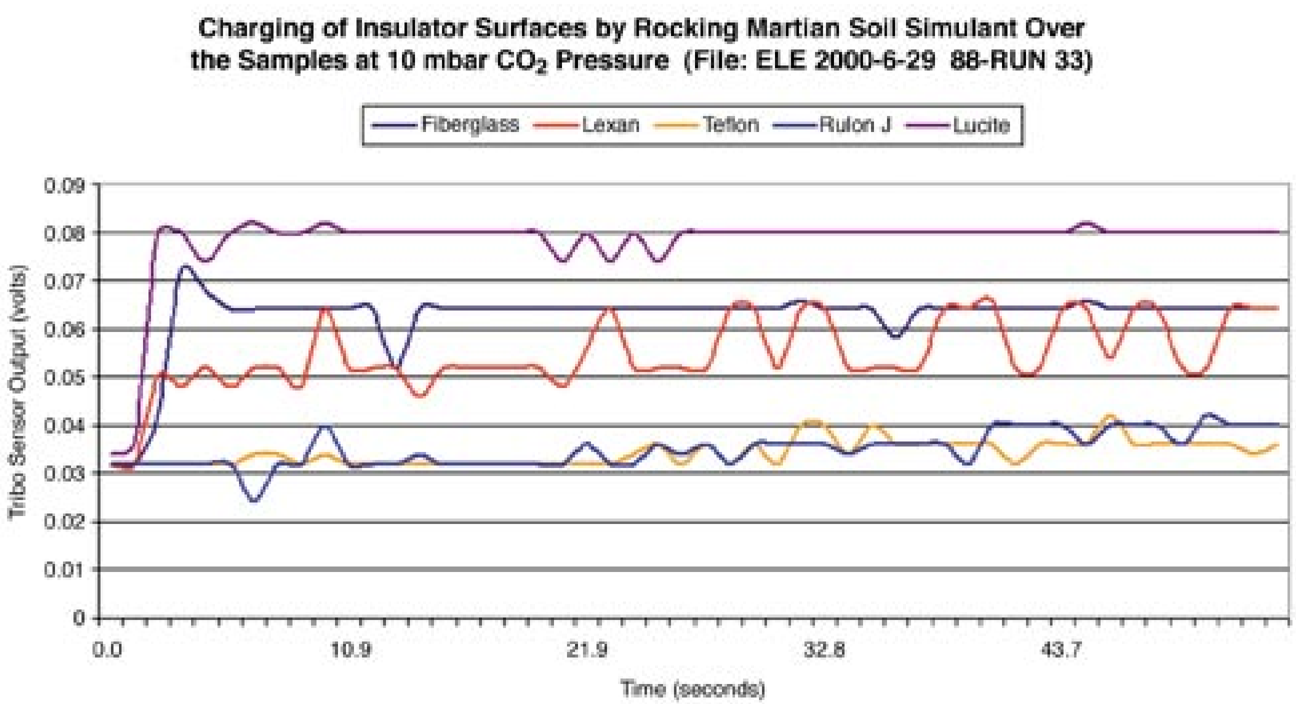

Figure 3. Typical Output in a Low-Pressure CO_2 Atmosphere

Assessment of Remote Sensing Technologies for Location of Hydrogen and Helium Leaks

The objective of this research effort is to reduce the cost of leak detection, location, and measurement by an order of magnitude. The objective of the initial phase of this research effort was to evaluate remote sensing technologies for location of leaks of gaseous molecular hydrogen (H_2) and gaseous helium (He) in air for space transportation applications. This research investigated remote sensing techniques rather than in situ techniques. An in situ technique is one that measures at the location of the sensor, while a remote technique is one that measures at some distance away from the sensor itself.

Eleven specific techniques were evaluated:

- Passive Sonar
- Active Sonar
- Differential Absorption Lidar (DIAL)
- Fourier Transform Infrared (FTIR) Spectroscopy
- Spontaneous Raman Spectroscopy
- Coherent Anti-Stokes Raman Spectroscopy (CARS)
- Rayleigh Doppler
- Indirect Thermal
- Rayleigh Intensity
- Schlieren Imaging
- Shearography

A full report was produced in which the principle of each technique is briefly described and a bibliography is provided listing references that describe each technique in detail. The applicability for location of H_2 and He leaks is discussed for each technique, with emphasis on the sensitivity, spatial resolution, and constraints (cost, size, field of view, ease of use, etc.). Quantitative models for expected performance are included for most of the techniques. The technological maturity of each technique for application to determining location of H_2 and He leaks is assessed in terms of the appropriate NASA Technology Readiness Level (TRL). The results of these evaluations are summarized in the table.

The objective of Phase 2 is to advance all techniques to the TRL 4 level to enable an informed comparison of all eleven techniques. Therefore, this Phase 2 effort will advance the Rayleigh Doppler technique from its current TRL 1 to TRL 3 or 4, along with advancing four other techniques from the current TRL 3 to TRL 4. In Phase 3, one or more of the most promising techniques would be advanced to the TRL 6 or higher level to provide for program acquisition and implementation.

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Participating Organization: Florida Space Institute (R.G. Sellar)

Technology Evaluation Summary

Technique	Distinguishing Characteristic	Measurement	Applicability	TRL
Passive Sonar	Turbulent airflow (ultrasound)	Acoustic intensity (passive)	Demonstrated Low spatial resolution Sensitivity depends on pressure and aperture	4
Active Sonar	Speed of sound	Phase of acoustic waves (active)	Low spatial resolution Sensitivity limited by clutter	3
DIAL	Allowable energy levels	Absorption of radiation at characteristic wavelengths (active)	None – absorption lines only in vacuum ultraviolet (UV)	-
FTIR	Allowable energy levels	Emission of radiation at characteristic wavelengths (passive)	None – absorption lines only in UV	-
Raman – spontaneous	Allowable energy levels	Shift in wavelength of inelastically scattered radiation (active)	H_2: Sensitivity of 2% demonstrated He: None – monatomic therefore no vibration	6
Raman – CARS	Allowable energy levels	Shift in wavelength of inelastically scattered radiation (active)	H_2: Sensitivity of 10 parts per million (ppm) demonstrated He: None – monatomic therefore no vibration	3
Rayleigh Doppler	Molecular/atomic velocities	Shift in wavelength of elastically scattered radiation (active)	Theoretically applicable for both H_2 and He	1
Indirect Thermal	Temperature	Variation in temperature of solids caused by nearby cryogenic gas or expanding gas (passive)	Clutter limited?	3
Rayleigh Intensity	Molecular/atomic cross-section	Intensity of elastically scattered radiation (active)	Limited by Mie scattering (particulates) Clutter limited?	3
Schlieren	Index of refraction	Refraction of radiation caused by spatial variations in index of refraction (active)	Sensitivity limited by clutter: $1° \sim 346$ ppm H_2 $1° \sim 461$ ppm He	4
Shearography	Index of refraction	Phase (path length) of transmitted radiation (active)	Sensitivity limited by clutter: $1° \sim 346$ ppm H_2 $1° \sim 461$ ppm He	5

Automatic Detection of Particle Fallout in Cleanroom Environments

Detecting particle fallout contamination is important for a variety of reasons, not only in the aerospace industry but also in a growing number of other areas. Particle contamination can degrade the performance of the optics on a satellite or even prevent its mechanical parts from functioning properly. Particles deposited on surfaces can ruin surface finishes such as paint or epoxy. The particles can contaminate the cleanliness of prepackaged foods, medicines, or medical instruments. Particle fallout contamination can easily ruin computer chips during the manufacturing process or even during packaging.

Traditionally, measurement of particle fallout contamination levels in a facility is accomplished by placing a witness plate for several weeks in the area where particle fallout is to be measured and then transporting it to a laboratory where particles are manually counted under a microscope. This process is tedious, time-consuming, and prone to human error as well as corruption caused by handling and transporting the witness plates. An automated in situ approach to these measurements using an Automatic Particle Fallout Monitor (APFM) was developed. The APFM is a quantitative (it directly counts particles) particle fallout monitor that measures the size and number of particulates collected on a witness surface representing contamination that collects on surfaces at the point of use. The APFM can measure particles as small as 5 micrometers in diameter and calculate their contribution to percent area coverage (surface obscuration). The instrument correctly processes irregularly shaped particles as well as fibers. The instrument provides a quantitative measure of the cleanliness of a room in accordance with MIL-STD-1246.

A prototype instrument was designed, fabricated, and tested in the NASA Contamination Monitoring Laboratory. The instrument was then tested alongside the standard 37-millimeter gridded witness filters in the Operations and Checkout (O&C) Building at KSC. The data given by these two methods compared very favorably.

The technology was licensed by the Aerospace Engineering Group of IDEA, LLC. NASA and IDEA then embarked on a joint development effort and produced the first commercial prototype instrument. This instrument was then tested in the Space Station Processing Facility at KSC. The instrument was tested alongside several gridded 37-millimeter witness filters as well as two witness plates from an Estek silicon wafer scanner. The data from these three methods again matched closely.

The APFM consists of a sensing head and a main processing unit. The sensing head, which can be located up to 100 meters from the main processing unit, contains a black witness surface on which particle contamination deposits through an opening in its top. The surface is imaged using two cameras, one looking for large particles (up to 1,000 microns in diameter) and one looking for small particles (down to 5 microns in diameter). These images of the witness surface are transmitted to the main processing unit.

The main processing unit receives images from sensing heads attached to it (there may be multiple sensing heads attached to one processing unit). It then analyzes each of the images it receives for particles. Identified particles are measured and categorized into size bins. Over time, the accumulated data gives information used in MIL-STD-1246 cleanliness calculations, and the rate of change of particle accumulation gives information about how fast contamination is accumulating at the current time.

The system also possesses its own ether port and an APACH web server so customers can monitor and retrieve fallout data remotely over a facility's intranet or via the internet.

Development and commercialization of this instrument are nearly complete. Testing demonstrated good agreement between these measurements and those made with other widely accepted measurement methods. The testing also adequately demonstrated the system's primary advantage over existing methods – the completely automated detection, analysis, and reporting of particles onsite without the need for extrinsic equipment or facilities.

Key accomplishments:

- Assembly and checkout of first commercial prototype.
- Assembly of second prototype unit.
- Field testing at KSC verifying the instrument's measurements are valid and accurate.
- Sale of first commercial units.

Key milestones:

- February 2001: Extension of distance from sensor head to controller to 100 meters.
- March 2001: Integration of a smaller system controller.
- April 2001: Improvement of graphical user interface.
- May 2001: Design and production of smaller sensor heads.

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Participating Organizations: IDEA, LLC (H.E. Rice and T.J. Mallow) and Dynacs Inc. (S.J. Klinko)

GMT-to-MET IRIG Time Code Simulator

NASA has two different upcoming flight projects incorporating an Air Transport Rack (ATR) that receives and decodes Greenwich Mean Time (GMT) and Mission Elapsed Time (MET) from the Shuttle orbiter timing buffer. A simulator is required to provide an Interrrange Instrumentation Group (IRIG) timing signal during ground testing of the ATR. The simulator will also provide and monitor power for the ATR and communicate through the serial and Ethernet data lines that interface with the ATR. Simulation of these data streams is necessary for electromagnetic interference (EMI), environmental, and functional testing.

A unique requirement of this simulator (and the feature that makes this simulator noteworthy) is the simulation of the time stream that the ATR will be required to translate. Prior to launch, the ATR will be receiving the IRIG standard time-distribution signal, IRIG-B GMT, to time-stamp data and use for other counting functions. At T-0, the ground link is separated from the Shuttle, and the time reference becomes the MET generated onboard. This time code format is specified in MC456-0051, Orbiter Master Timing Unit Specification, section 3.2.1.5.3. The Time Translator Module of the ATR is required to synchronize to the change within 2 seconds.

Since T-0 can occur anywhere within the IRIG-B frame, the Time Translator Module should be tested as thoroughly as possible to ensure it synchronizes within the required 2 seconds regardless of where the break occurs. In the past, testing of this function was limited to the playback of files created using a recording oscilloscope. This simulator will enable exhaustive testing by allowing operators to insert the T-0 transition anywhere in the signal stream and, as a result, will provide a higher confidence that the Time Translator Module will perform adequately during launch. The figures illustrate the requirements of the Time Translator Module and the task of the simulator.

Figure 1 represents 019:13:01:59. The differential timing signal generated by this simulator only generates codes in the binary coded decimal (BCD) time-of-year portion of the signal. The control functions and time of day in seconds are generated as blank timing frames. (See IRIG Standard 200-98 published by Secretariat: Range Commanders Council: U.S. Army White Sands Missile Range, New Mexico 88002-5110: http://jcs.mil/RCC/ for further information about the IRIG standard.)

Figure 2 shows a perfect transition from 019:13:01:59 GMT to 000:00:00:00 MET. The double index (see the arrow) indicates this transition. In operations, a perfect transition from GMT to MET is almost never received. As much as 2 seconds of the timing signal can appear to be skipped without an actual loss of the signal. Since the last part of all frames is blank (no control functions or time of day) and the entire first MET second consists of blank frames, it is impossible to tell exactly where the skipped signal occurs.

Figure 3 is an example of the type of faulty transitions from GMT to MET that can occur. In this case,

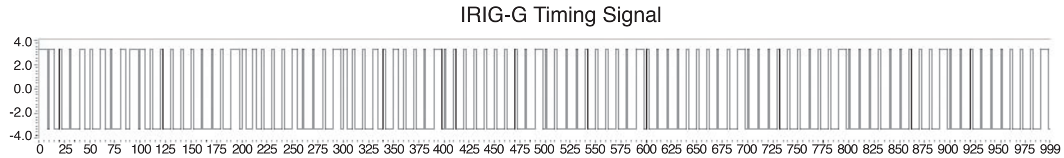

Figure 1. Signal Represents 019:13:01:59

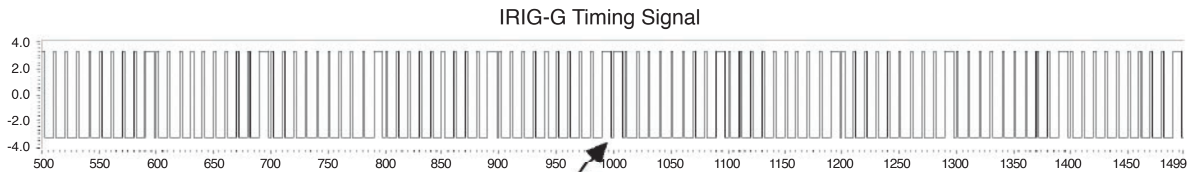

Figure 2. Transition From 019:13:01:59 GMT to 000:00:00:00 MET

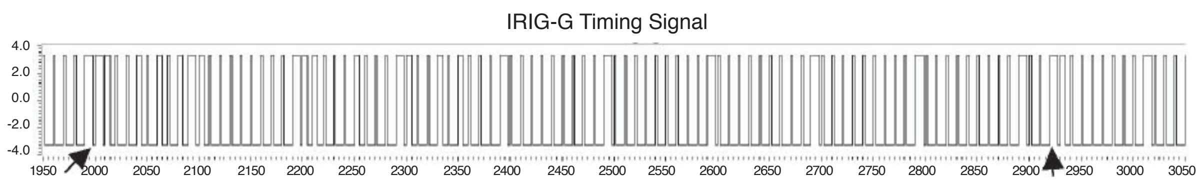

Figure 3. Faulty Transitions From GMT to MET

the 019:13:01:59 starts (left arrow) and nearly completes, but MET 000:00:00:01 starts (right arrow) without the double index pulse. In many of the transitions, it appears the last GMT second has been extended, but because the blank frames look the same as MET 000:00:00:00, there is no way to tell. The simulator can replicate these transition glitches and be used to test a given IRIG-B decoder to verify it performs within specifications.

The abrupt change from GMT to MET and the often missing double index pulse at the start of a second cause many IRIG-B decoders to report the incorrect time until they have synchronized to the new signal. The current requirement is for the IRIG-B decoder to report the correct MET within 2 seconds of the GMT-to-MET transition. The simulator will enable testing of any IRIG-B decoder to verify it can synchronize to the signal within 2 seconds of the GMT-to-MET transition.

Key accomplishment:

- Developed and tested the simulator.

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Participating Organization: Dynacs Inc. (B.M. Burns, Dr. P.J. Medelius, J.S. Moerk, A.J. Eckhoff, J.D. Taylor, J.J. Henderson, and J.A. Rees)

Remote Access, Internet-Based Data Acquisition System

Current outreach efforts for KSC's Beach Corrosion Test Site require all experimentation and data collection be conducted by onsite personnel on a real-time basis. This restricts the amount of work conducted at the site because of personnel constraints. A Remote Access, Internet-Based Data Acquisition System will establish a basis for the Corrosion Technology Testbed to allow personnel and customers to conduct their experiments from remote locations using the Internet.

This state-of-the-art pathfinder acquisition system could be utilized as a model for other NASA and KSC laboratories to directly develop their capabilities without the resulting impact to personnel and travel expenses. In addition, successful development and continued optimization of this system will produce great interest in NASA/KSC for corrosion research, corrosion exposure contracts, and industry partnerships. The benefits of this project include:

- Showcasing NASA/KSC's outreach efforts through interactivity and state-of-the-art innovative technologies.
- Establishing a Corrosion Technology Testbed for use by other NASA laboratories.
- Allowing direct outreach of the KSC Beach Corrosion Test Site to customers around the country and around the world.
- Allowing customers to conduct corrosion research without the travel requirements to the exposure site.
- Allowing business expansion at the site without the direct need for additional personnel.
- Developing network solutions to allow remote operation of experiment and data collection systems.
- Developing software with security features that allow outside customers to have data access at a KSC site.
- Testing the resulting systems to prove feasibility and optimize user interface and expansion capabilities.

This interactive system will have significant commercial applications for outreach to corrosion research laboratories, the corrosion control industry, Government laboratories, paints and coatings industries, and the marine technology industry.

Key accomplishments:

- Installed a 50-data-channel network from the exterior exposure site to the interior of the KSC Beach Corrosion Test Site for monitoring remote access corrosion experiments.
- Created an accessible Web site to interact with the KSC Beach Corrosion Test Site experiments.
- Integrated software and hardware to provide a secure and reliable system to monitor and control data acquisition computers.
- Developed data acquisition software to interface with the Internet.
- Collected data from 15 remote experiments proving the concept.

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Participating Organization: Dynacs Inc. (J.B. Crisafulli and J.J. Curran)

Portable Cart To Support Hypergolic Vapor Detection Instruments

The processing of payloads at KSC requires the handling of hypergolic propellants used to control the payload while in orbit. These propellants are toxic and workers in an area must not be exposed to concentrations greater than those allowed by KSC regulations. To ensure the safety of people working around a payload after it has been loaded with fuel, the air in the work area is monitored to detect concentrations close to the allowed limit. The limit is 0.01 part per million (ppm) for hydrazine fuels and 1 ppm for nitrogen tetroxide (N_2O_4) oxidizer.

The MDA Single Point Monitor (SPM) is an instrument used to monitor these vapors. It is designed to be permanently mounted in a hazardous environment on a wall or a panel. To use the instrument effectively in a payload processing facility, the instrument needs to be close to the payload being monitored. The SPM was mounted on a small laboratory cart to make the instrument mobile and to provide more audible and visible alarm signals. The cart provides power and purge gas to the sensor and accepts the sensor alarm relay closures to activate a beacon and buzzer mounted on the cart. The SPM cart is a small stainless-steel laboratory cart modified to add an electrical enclosure, an explosion-proof annunciator, and a three-color beacon. This cart is designed to operate in a hazardous environment. All the enclosures are NEMA 4/4X type, purged with nitrogen gas. The electrical power is interlocked to the purge switch that interrupts power to the SPM if the purge pressure fails. The SPM purge switch will not interrupt power to the alarms or the alarm relays inside the SPM. There is a second purge pressure switch inside the cart enclosure that is closed when the purge pressure exceeds 0.5 inch of water column. This switch interrupts power to all circuits in the cart and the SPM when purge pressure fails.

The SPM cart provides two annunciators – a beacon that produces three different colors and a buzzer that produces 89-decibel sound measured at a distance of 10 feet. The beacon is mounted on a stanchion on one end of the cart at about a 5-foot elevation. The stanchion is a conduit that carries both electrical power and purge gas pressure to the beacon. The buzzer is mounted on the top shelf of the cart, which is connected to the control enclosure by a tube that carries both electrical power and purge gas pressure to the buzzer. The beacon is green and steady during normal operation, serves as a pilot light for the cart, and can be seen from a distance as an indication that power to the SPM is on. In the event of a power loss, blown fuse, or loss of purge, the beacon goes out and the SPM stops operating. In the event of an instrument alarm signal from the SPM, the beacon changes to flashing yellow. This occurs when the SPM internal health checks detect a failure condition such as the loss of the sample flow or out-of-tape. When the SPM detects a concentration of fuel or oxidizer vapor in excess of the preset alarm limits, the beacon changes to flashing red and the buzzer sounds.

Key accomplishment:

- Designed and constructed two SPM carts.

Key milestone:

- Two SPM carts supported the Mars Odyssey payload and are currently in use in the Spacecraft Assembly and Encapsulation Facility II.

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Participating Organization: Dynacs Inc. (C.B. Mattson, P.W. Yocom, T.R. Hodge, S.L. Parks, D.N. Bardel, and Dr. B.J. Meneghelli)

The SPM is located at the right side of the top shelf. The power and alarm controls are located in the box on the left side, with the beacon on top. The power cord is coiled and stowed on the bottom shelf when not in use.

Personal Cabin Pressure Altitude Monitor and Warning System

Kennedy Space Center has developed an aviation/aerospace safety device designed to warn crewmembers of a potentially dangerous or deteriorating cabin pressure condition. About the size of a large pager, the Personal Cabin Pressure Altitude Monitor and Warning System operates independently of other aircraft/spacecraft systems and tracks the pressure conditions of the local environment. The monitor warns (by means of audio, vibratory, and visual alarms) of the impending danger of hypoxia when cabin pressure has fallen to preprogrammed threshold levels. A lighted digital screen displays a text message of the warning and annotates the pressurization condition causing the alarm.

The current model contains a miniature, but highly accurate, pressure transducer. Its readings are further enhanced by employing a collocated temperature sensor to thermally compensate the device. The unit is microprocessor based and is used to interface the sensors, displays, and alarms as well as operate the embedded code to solve the mathematical algorithm that converts the indicated pressure readings to altitude. Through panel-switch selection, the user can choose the units of the altimeter to be displayed (i.e., feet or meters), the units of temperature (degree Celsius or Fahrenheit), and whether to indicate the altitude above ground level (AGL) or above mean sea level (MSL). When the device is used as an altimeter, the user can also select the current altimeter (pressure) setting for either pressure altitude or indicated altitude display. The user can further choose which set of Federal Aviation Administration (FAA) flight rules the unit is to monitor – either commercial [Federal Aviation Regulation (FAR) Part 121/135 or noncommercial (FAR Part 91)] operations.

Cabin Pressure Altitude Monitor

Hypoxia is a state of oxygen deficiency in the blood, tissues, and cells sufficient to impair functions of the brain and other organs. Because the partial pressure of oxygen is reduced as altitude increases, hypoxia is a concern to flight crews when flying above 10,000 feet cabin pressure altitude. The symptoms of hypoxia often go unrecognized because the brain is the first organ to be affected. Once hypoxia occurs, it is difficult, and often impossible, for the person to acknowledge the situation or to take corrective action. In the early stages, there is considerable loss of judgment and cognitive ability. Performance can seriously deteriorate within 15 minutes at altitudes as low as 15,000 feet. The ability to take action is lost in 20 to 30 minutes at 18,000 feet and in 5 to 12 minutes at 20,000 feet. At 35,000 feet, the time of useful consciousness is a mere 30 to 60 seconds.

Throughout aviation history, there have been numerous incidents in which aircraft crewmembers and/or passengers have been incapacitated by hypoxia. The most compromising condition leading to hypoxia is not the immediate and recognizable rapid decompression, but one in which a slow yet significant leak has developed in the pressurized cabin or cockpit of an airplane. With crewmembers and passengers unaware, they may either simply fall asleep or be otherwise unknowingly incapacitated. Though many aircraft are fitted with cabin pressurization, monitoring, and alerting systems, there are situations in which the onboard system fails or is misconfigured, rendering the occupants or crew totally unaware of a deteriorating, low-oxygen environment. Another situation is one in which the pilot either knowingly or unwittingly ventures too high for too long in a nonpressurized aircraft.

The aviation application for the monitor includes monitoring and protection for both scenarios. For pressurized aircraft, the invention provides an independent warning of cabin pressure altitude when a cabin leak or other reason for pressurization loss might go undetected. For nonpressurized aircraft, the monitor tracks the time and altitude profile of the cockpit in accordance with prescribed regulations and provides a warning to the crew when supplemental oxygen is to be used.

Human space operations can also benefit from the innovation in Low-Earth-Orbit (LEO) vehicles such as Space Shuttle, Space Station, and Mir, as well as long-duration interplanetary vehicles and future planetary habitats. The proposed ground-based applications include the Mars simulation chamber at KSC and the various pressure/vacuum test chambers at NASA's Space Flight and Research Centers. Applications in its existing form, beyond aviation and aerospace, include use as an altimeter and thermometer for mountain climbers and as a barometer and thermometer for meteorological measurements. With the selection of a different pressure transducer and modification to the software, the device could be used to track the pressure, depth, and time profiles in human-tended underwater habitats and hyperbaric chambers.

The cabin pressure monitor has undergone a fast-track development effort in 2000, going from concept to flight demonstrator units in less that 9 months. The flight units were tested in the laboratory, in an altitude chamber where normal ascent and rapid decompression profiles were flown, and in various pressurized and nonpressurized aircraft. The technology was introduced to the public in the summer at the Experimental Aircraft Association (EAA) Airventure 2000 airshow held in Oshkosh, Wisconsin. An industry briefing followed in October with commercialization efforts well underway.

Key accomplishments:

- Developed first- and second-generation working prototypes for general and commercial aviation use.
- Tested demonstrator units in the laboratory, an altitude chamber (including explosive decompression), and a variety of aircraft environments.
- Introduced the unit to the public at the EAA Airventure 2000 air show in Oshkosh, Wisconsin.
- Applied for a NASA patent.
- Held an industry briefing and initiated technology transfer and commercialization efforts.

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Integrated Network Control System

The Integrated Network Control System (INCS) is a highly reliable and highly automated network system that sends data and commands between the Shuttle Launch Control Center (LCC) and the hardware end items. INCS will bridge modern industry automation technologies with customized aerospace industry communication protocols and associated legacy end item equipment. The INCS design is meeting several challenges including connectivity with 40,000 end items located within 28 separate ground systems, all dispersed to 10 facilities over 16 square miles. The INCS design must also provide data reliability, integrity, and emergency safing systems to ensure successful and safe launch operations.

Ground control and instrumentation systems for the Space Shuttle Launch Processing System (LPS) use custom digital-to-analog hardware and software connected to an analog wire interconnect distribution system. Loss of a data path during critical operations both before and immediately after launch would greatly compromise safety. To enhance safety, data integrity, and network connectivity, INCS design uses three separate networks: (1) the Command and Control Network, (2) the Emergency Safing Network, and (3) the Health Management Network.

For both the command and control bus and the emergency safing bus, INCS chose a redundant media network topology. Unlike most control networks, this unique network can transmit or receive identical data over two separate paths at the same time. Therefore, loss of communication over one channel would not affect operations on the other. The data can also be scheduled, thereby easily prioritizing time-critical over noncritical data, while providing absolute assurance that critical measurements arrive on time. This greatly reduces startup, configuration, and validation test times because data is typically prioritized using software interrupts that increase engineering, testing, and software debug times.

The network topology uses a quad redundant, fiber-optic, fault-tolerant ring for long-distance distribution over the LCC, Mobile Launcher Platforms (MLP's), Orbiter Processing facilities (OPF's), and two launch pads. Shorter distances will accommodate redundant media with coaxial cable (two per channel) for distribution over system and subsystem levels. The network will reduce cable and wiring for ground processing over the Launch Complex 39 area by approximately 80 percent and cable interconnects by 75 percent. This will enhance processing by reducing maintenance and troubleshooting.

To achieve critical data integrity and not burden the control network with increased traffic, the Health Management Network is separate from the Command and Control bus. Over Ethernet, unscheduled data from the backplane of the local gateways will pass detailed parameters of end items, such as motor drives, soft starts, valves, switches, process controller, and sensors.

The Health Management Network is used to configure the system and monitor the health and availability of the entire network and most end items. By integrating alarm, system, and network information onto a single screen, the user could receive instant problem notification and the exact location anywhere on the network. Since one end item can have as many as 400 parameters, it is essential and beneficial that large amounts of information can be utilized for many purposes while not interfering with critical process control.

Process enhancements are achieved through quickly pinpointing problems and enhanced remote control capabilities. These include open-wire detection of various sensors, override of instrumentation anomalies, remote reset of fuses, and in-depth health information of various end items.

The INCS network health information system would be useful for test facilities and prototype flight support systems in which fast startup times, accurate instrumentation, and versatility may be desired. Multiple configurations and measurements can be brought online, configured, and integrated onto a graphical screen within a few days. Changes such as scaling, zero and span calibrations, process control tuning, and parameter adjustments can be made in real time. New end items can be configured, brought online, and communicating within minutes. Remote and local automated control is available through distributed controllers and peer-to-peer communications. Design and network versatility is achieved using a gateway chassis capable of many configurations. The control chassis can be: (1) a network bridge, bridging various network protocols, or a control gateway; (2) a process controller with PID control loops and input/output (I/O) devices; (3) simple remote I/O control; or (4) any combination of the three.

This provides design flexibility and versatility because many configurations are available to the user at any time, now or in the future. The network bridge will serve to provide connectivity to the system end items, accommodating both new and legacy (old) equipment. To preserve network integrity, INCS prefers to limit the use of network protocols. INCS is also developing a driver for the Institute of Electrical and Electronics Engineers (IEEE) 488 used for the Range Safety and Telecommunications systems.

At the LCC, a VME-based interface bridge was developed to map data from the INCS Command and Control bus to the custom 1553 Manchester-II Shuttle Ground Data bus. The interface bridge was designed to work with both software control systems used in the firing rooms of the LCC – the existing Command Control and Monitor System (CCMS) and the new Checkout and Launch Control System (CLCS), when implemented. This provides the dual benefit of being able to implement INCS at any time and to transition to either system with minimal impacts. The INCS would be the first large-scale network control and health management system for the Space Program and one of the largest fully integrated control networks in the world.

Key accomplishments:

- Proof-of-concept document and system-level specification signed and released.
- Comprehensive cost estimate and master schedule completed.
- Database of 40,000 I/O points, the associated end items, distributors, cables, etc., built.
- Basic design and architecture with equipment location list and single-line diagram of system layout completed.
- Environmental testing of hardware field vibration testing and vibrational analysis of remote distributors (Node Boxes) installed on both pads and 1 MLP 80 percent completed.
- Successful testing of VME-based interface bridge connected to CCMS in firing room 3.
- Emergency safing system design using active standby with safety and reliability assessment 80 percent completed.
- INCS demonstrator located in LCC and successful testing of fiber modems for long-distance fiber transmission losses over multimode and singlemode fiber completed.

Key milestones:

- Complete development and testing of active standby for the VME-based interface bridge. Release of master transition plan document. Successful end-to-end testing from the LCC to Launch Pads A and B.

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Participating Organizations: United Space Alliance (K.J. Ahrens, R. Brown, and N. Mizell) and Dynacs Inc. (S.J. Romine)

By distributing data over the network, as opposed to wiring through terminal boards, the dual-channel redundant media network module on the left easily replaces the roomfull of terminal distibutors (center). On the right is an open terminal distributor showing cable and wiring.

Advanced Hazardous Gas Detection System

NASA routinely employs instrumentation for monitoring areas within the Space Shuttle for leaks in the cryogenic fuel system. Target gases of interest include hydrogen (the cryogenic fuel), oxygen (the cryogenic oxidizer), helium (an area purge gas), and argon (a marker for ambient air leaks) in a nitrogen background.

To date, quadrupole-based residual gas analyzers (RGA's) and fixed sector mass spectrometers are located between 200 and 400 feet from the vehicle sampling locations because of ruggedness requirements and size limitations. Recent efforts focused on evaluating and testing a variety of novel and/or miniaturized mass analyzers for possible use in supporting future launches. The mass spectrometers will be placed close to the vehicle to eliminate the need for the long sample lines. This close proximity will improve the response time and sensitivity of the instrument and, at the same time, will necessitate making the instruments smaller and more rugged. Sensor and spectroscopy instrumentation were considered but mass spectrometry (MS) appears to be the best suited for this application. MS instruments currently being evaluated include all of the commonly known mass analyzers [i.e., quadrupole, sector, time-of-flight (TOF), quadrupole ion trap, and Fourier transform ion cyclotron resonance (FT-ICR)] as well as novel and/or hybrid designs (i.e., multi-quadrupole, cycloidal focus, and a cylindrical crossed electric/magnetic sector). Each of these instruments is being characterized through ongoing laboratory tests using gas standards. The aim of this research is to determine which mass analyzer technology is best suited for this application.

The instrumentation must detect concentrations of hydrogen and oxygen as low as 25 parts-per-million by volume (ppmv) and argon concentrations as low as 10 ppmv. In addition, the instrumentation must have a linear dynamic range of four orders in magnitude and provide a unit mass resolution across this range. The system deployed on the Shuttle launch pad should be low in volume and weight, be rugged enough to withstand the strong vibrations that occur during Shuttle launches, provide response times of less than 5 seconds, and supply updated concentration data every second.

For these experiments, the quadrupole RGA was used as the standard against which the other mass spectrometers were compared. Quadrupole RGA instruments are widely used for detecting low levels of permanent gases for various process monitoring applications and, therefore, are able to meet many of the desired performance criteria. They can have computed accuracies to within 2 percent, which is well within the 10-percent performance specification. They are not small or rugged enough, however, for the stated application. In addition, the update rate is too slow.

Several different quadrupole ion trap instruments coupled to various sample introduction systems were also tested. Commercial quadrupole ion trap instruments were not designed for permanent gas analysis and are not capable of scanning below mass to charge (m/z) 10. Some of the original research on quadrupole ion traps showed that they can indeed be used to detect hydrogen and helium, and research is in progress to make the necessary hardware modifications to the commercial instruments to achieve this end.

Two other instruments showing promise for this application are a prototype double-focusing electric-magnetic sector and TOF instruments. This sector instrument is a substantially miniaturized mass analyzer that easily fits in the palm of a hand. Results from this instrument indicate limits of detection (LOD's) as low as 9 ppmv (see the table). The TOF instrument gave marginal LOD's but poor response times. Future work on the inlet system may address this.

Representatives of two additional MS technologies, FT-ICR and multiquadrupole arrays, have shown less-than-promising results. Poor performance of the FT-ICR system was attributed largely to the engineering design. A small ion cell and a poorly devised vacuum system explain the high LOD's and extremely slow response times. It is unlikely the high vacuum requirements for this instrument are compatible with miniaturization or with the high sample pressures and flow rates necessary for fast response times. The multiquadrupole system provided better performance but exhibited high limits of detection. In addition, the system displayed poor sensitivity, specifically towards oxygen.

A comparison of the various figures of merit and other specifications from the mass analyzers evaluated to date are shown in the table. The quadrupole RGA instrument has yielded the best performance to date. It can rapidly achieve operating pressures and operational specifications within a few minutes after power-up and has proven reliability. The quadrupole ion trap instruments require further development to access the low masses necessary for this application and are affected by operating conditions such as temperature and pressure. The dual-sector and TOF instruments also show promise but likewise require further research and engineering to meet the requirements for this application.

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Participating Organization: Dynacs Inc. (Dr. T.P. Griffin, A. Ottens, and CR. Arkin)

Comparison of Selected Performance Specifications From the Various Mass Spectrometers Evaluated to Date

Type of Mass Analyzer	Limit of Detection (ppmv)				Mass Range (m/z)	Data Update (s)	Volume (cc)
	Hydrogen	Helium	Oxygen	Argon			
Quadrupole	1.8	0.2	1.6	0.6	2 - 100	6	50,500
Quadrupole Ion Trap	--	--	6	3	10 - 600	< 1	107,600
Dual Sector	173	79	19	9	2 - 50	~ 1	N/A
Cycloidal Focus	12	7	37	3	2 - 50	~ 30	54,700
TOF	54	18	204	17	2 - 50	1	121,800
Multipole	> 500	~ 500	>> 500	>> 500	2 - 50	~ 7.5	35,100
FT-ICR	> 5000	> 5000	> 21000	> 5000	--	--	104,800

Hazardous Gas Detection System 2000

The Space Shuttle uses liquid hydrogen and liquid oxygen as the fuel and oxidizer, respectively, for the main engines. Because of the hazards associated with these commodities, it is important to ensure the main engines do not leak. From the beginning of the Space Shuttle program, mass spectrometers have been used to monitor for cryogenic fuel leaks. Mass spectrometry is the only technology proven to monitor all necessary gas constituents at the required limits of detection [low part per million (ppm)]. Currently, four mass spectrometer-based systems are used for each launch: Prime Hazardous Gas Detection System (HGDS), Backup HGDS, Portable Aft Mass Spectrometer, and Hydrogen Umbilical Mass Spectrometer. Due to the age of the Prime and Backup HGDS's, long downtimes are a frequent occurrence, extensive maintenance is required to keep them operational, many of the system components are obsolete, and overall system performance is degrading. Also, these four systems contain eight-bit control systems that require a unique and cumbersome data monitoring system. A new gas detection system was needed to improve operational performance and system maintainability. The replacement system is the Hazardous Gas Detection System 2000 shown in figure 1.

Figure 1. HGDS 2000

Many features of the new HGDS 2000 were not in the previous systems. These features include the Multiple Detector Sample Delivery System, control of the inlet pressure, use of an inexpensive (less than $6,000) quadrupole mass spectrometer, new pump technologies for backing as well as for transport (which alleviates the need for costly, hazardous pump oil), and expanded monitoring and control systems. The use of the latest technologies in mass spectrometry and pumps yields a quieter, more robust system that helps to improve astronaut safety, as well as safety for engineers and technicians operating the system. This is the first system designed from the ground up with the full redundancy and functionality necessary for criticality 1 ground support equipment (GSE). The system is capable of monitoring gases in helium, nitrogen, or air backgrounds. The mass spectrometer enables near-simultaneous (within the speed of the electronics) monitoring of all gas constituents of interest. All these features contribute to achieving limits of detections in the low-ppm range with a response time of less than 10 seconds.

Figure 2 depicts an overview of the entire HGDS 2000. The Multiple Detector Sample Delivery System is used to deliver gas samples to the inlets of two independent mass spectrometers. All aspects of the operation of the system are controlled through the VME system with addi-

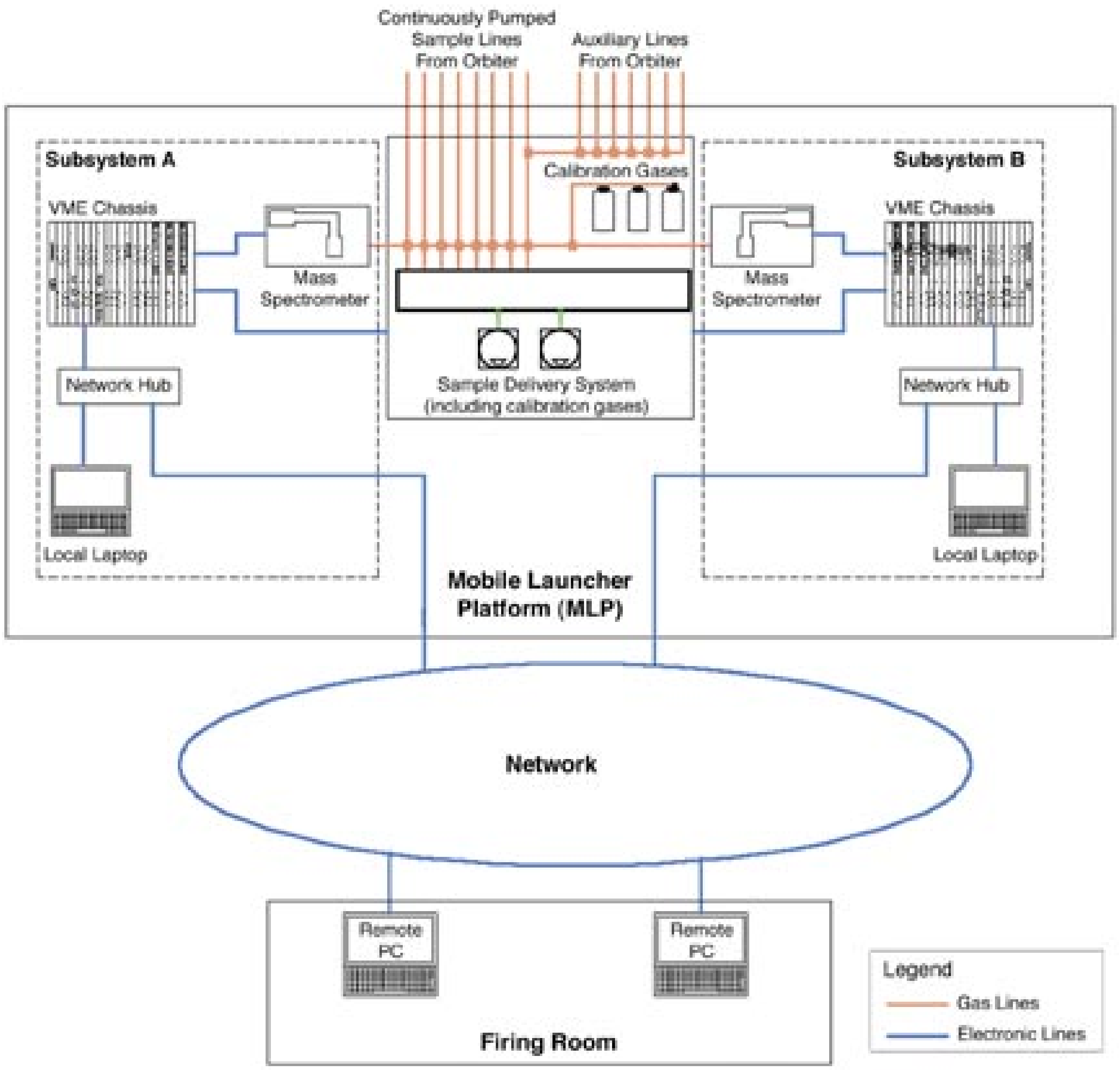

Figure 2. Block Diagram of HGDS 2000

tional control and communication cards, as required. Gas concentrations are reported in both ppm and percent (%). Information is sent to personal computers (PC's) connected to the VME by an independent, redundant network. All user interaction is performed using the PC.

The system is fully redundant and meets all requirements for GSE. This includes ruggedness to withstand launching on the Mobile Launcher Platform (MLP), ease of operation, and minimal operator intervention. User inputs are through the PC using mouse and keyboard commands. The interface is intuitive and easy to operate. The project is a successful demonstration of using commercial off-the-shelf (COTS) items along with in-house designs to produce a system that is uniquely suited for on-line gas monitoring. Though this system is currently optimized for detecting cryogenic leaks, many other gas constituents could be monitored using the HGDS 2000.

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Participating Organization: Dynacs Inc. (Dr. T.P. Griffin, G.R. Naylor, W.D. Haskell, and R.J. Hritz)

Leak Detection Point Sensors for Gases

This is a research and development project to design and fabricate point gas sensors and to identify commercial point sensors for leak detection. Ultimately, these sensors will be used for locating propellant leaks in ground support equipment (GSE), the Space Shuttle aft engine compartment, and future-generation spacecraft. In order to verify candidate sensor performance, a multipurpose Point Sensor Test Platform was to be designed, fabricated, and verified. All sensor testing will be conducted according to a new guideline document being produced in the project (KSC-YA-5381, KSC Gas Detection Instrumentation Test and Qualification Guideline).

A comprehensive survey was conducted to determine which sensors are commercially available and which sensors are in an active development project. A broad search was conducted to include propellant gases and contaminants, purge gases, and those gases associated with Mars in situ propellant production. In particular, the gases of interest were hydrogen, oxygen, nitrogen tetroxide, monomethylhydrazine, nitrogen, argon, helium, water vapor, carbon dioxide, and carbon monoxide.

The Point Sensor Test Platform, formerly called Bantam X, has been completed and is housed in the Engineering Development Laboratory at Kennedy Space Center. An environmental chamber has the capability of testing at temperatures from -60 to +100 degrees Celsius, pressures from 20 to 1000 torr, and various gas concentrations with up to five gas cylinders along with a sixth cylinder for zero gas. LabView software enables essentially automated control and sequencing of various test conditions and simultaneously acquires the test data.

The work currently in progress includes:

- Final modifications of the Point Sensor Test Platform to include dynamic testing of sensor time response and drift stability.
- Documentation, manuals, parts list, and drawings.
- Validation of the Point Sensor Test Platform hardware and software performance.

This program will provide the following benefits:

- Establish a KSC standard for sensor testing.
- Qualify sensors for realistic flight and ground support environmental conditions.
- Establish a baseline for sensor development and availability.
- Shorten vehicle-processing time in the long range.

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Point Sensor Test Platform

Biological Sciences

Biological Sciences is the science core competency area for the Spaceport Technology Center. This has the vision of achieving a better understanding of managing biological and ecological systems for applications in space and on Earth. To accomplish this vision, research and technology development will be performed to develop a baseline data set for biological system stability and capability for missions beyond low Earth orbit (for example, bioregenerative life support system), to develop an understanding of the fundamental issues with biological organisms in microgravity, to assess environmental impacts on new and old launch sites on Earth and eventually other planetary bodies, and to ensure our ecosystem at KSC is understood, managed, and protected.

Activities/focus areas include the following:

- Bioregenerative Life Support
- Basic Biological Research
- Spaceport Ecosystem Sciences

The goals and objectives of Biological Sciences include the following:

- Perform fundamental research in bioregenerative life support and plant responses to microgravity as part of the Advanced Life Support (ALS) and Fundamental Biology Programs
- Conduct a controlled biological systems research and development effort that will generate the research data and technology required to build functioning bioregenerative life support systems for long-duration space missions
- Improve KSC research and technology capabilities to meet operational requirements in the areas of environmental compliance and laboratory support of flight experiments
- Provide the scientific understanding and technologies needed to support the sound management and conservation of our Spaceport Technology Center's ecological resources

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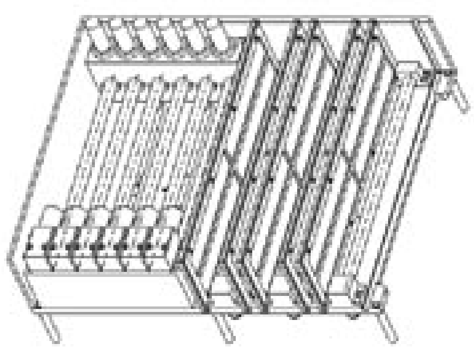
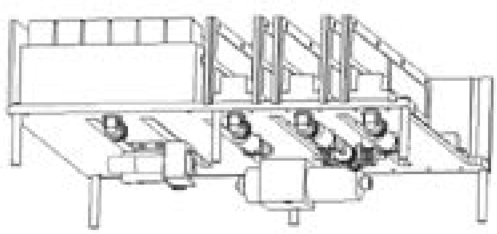
Evaluation of Two Microgravity-Rated Nutrient Delivery Systems Designed for the Cultivation of Plants in Space

There is a need for microgravity-based plant culture nutrient delivery systems (NDS's) for both bioregenerative Advanced Life Support and plant research functions. The provision of adequate levels of water (without causing waterlogging) and oxygen to the root zone is the most crucial component deterring major advancements in this area. The dominance of the surface tension of water under microgravity conditions has often been found to lead to either severe waterlogging or excessive drying in the root zone. Consequently, differences in plant growth responses between spaceflight experiments and their ground controls are expected based merely upon differences in moisture distribution patterns between the two conditions.



PTIM Model Top View



PTIM Model Bottom View

This project addresses the question of "comparability of environmental conditions" between the spaceflight and ground control experiments for both a porous tube plant NDS and a substrate-based NDS by employing three different wetness-level treatments for both of these approaches. It is anticipated that different preset wetness levels than those used on Earth will be required to support optimal plant growth in space. Dry seeds will be loaded 3 days prior to orbiter liftoff, and the system will be initiated by the crew on-orbit. A minimum of 72 wheat (Triticum aestivum) seeds (for each of the two NDS's) will be imbibed and germinated on-orbit. A time-lapsed video recording of the plants will monitor the growth over time. At recovery, the plants will be measured, and tissue will be analyzed for gene expression and stress-associated metabolites.

The Porous Tube Insert Module (PTIM) prototype apparatus (see the figures) is the testbed for the development of experimental procedures for this spaceflight experiment. PTIM provides water delivery to both a series of "naked" porous tubes and porous tube/substrate compartments. PTIM software will allow the crew to interact with the PTIM system's watering initiation protocols. The PTIM incorporates several types of sensors (e.g., pressure and moisture) to determine the wetness levels both on the "naked" porous tubes and within the three substrate compartments of the module.

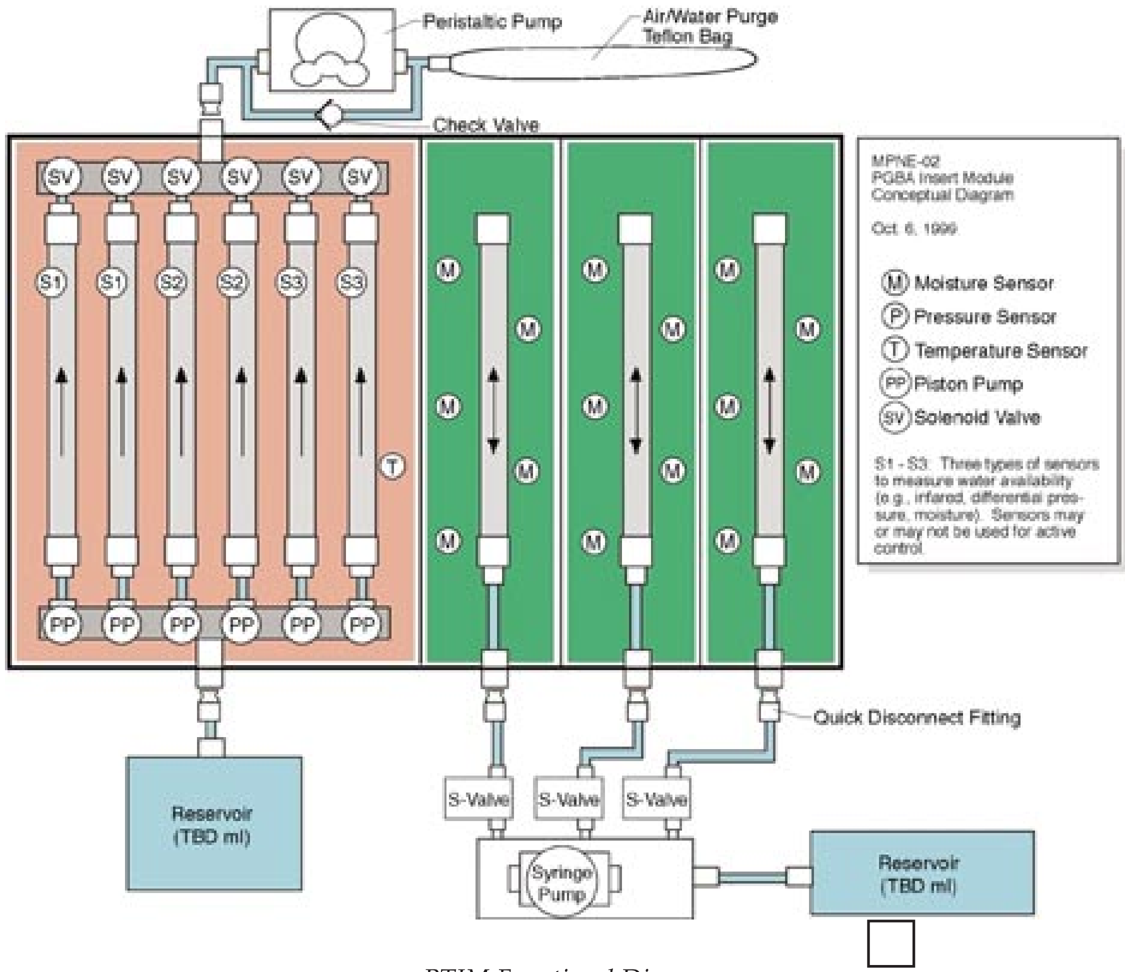
Key accomplishments (2000):

As part of the Year 1 Development Phase of the project, the following tasks were accomplished:

- Identified basic hardware configuration options.
- Performed ground studies to define experimental methods and requirements.
- Developed and undertook science testing with the PTIM prototype apparatus.

Key milestones:

- 2001: Perform KC-135 testing of critical hardware designs. Conduct a high-fidelity science verification test using the flight hardware configuration.
- 2002: Complete flight hardware fabrication. Conduct a high-fidelity payload verification test using flight hardware.
- 2003/2004: Conduct a spaceflight experiment on the Space Shuttle.



PTIM Functional Diagram

The photo to the left shows wheat plants grown for 18 days on the PTIM prototype unit. The left half of the unit contains six porous tubes at varying pore sizes ranging from 0.2 to 0.3 micrometer, each of which received nutrient solution at a rate of 1 milliliter per hour. The right half of the unit consists of three substrate compartments that received different volume injections of water daily.

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Participating Organizations: Dynamac Corporation (Dr. H.G. Levine and Dr. T.W. Dreschel), Bionetics Corporation (H.W. Wells and K.A. Burtness), and BioServe Space Technologies (Dr. A. Hoehn)

Pilot-Scale Evaluation of a New Technology To Control Nitrogen Oxide (NO_X) Emissions From Stationary Combustion Sources (Phase III)

NO_X emissions from combustion sources such as power plants and incinerators have become an increasing environmental concern during the past several decades. In a cooperative agreement for a pilot-plant study, NASA, the University of Central Florida (UCF), and EKA Chemicals, Inc., have been experimenting for the past 3 years with relatively new and economically attractive methods of oxidizing the NO_X emissions with hydrogen peroxide (H_2O_2). Using a 35-million British thermal unit (Btu) natural-gas-fired industrial boiler onsite at KSC, nitric oxide (NO) and sulfur dioxide (SO_2) were injected into a portion of the flue gas prior to the experimental equipment in order to simulate a range of exhaust streams encountered in stationary combustion sources. Several methods were used to activate the H_2O_2 into hydroxyl radicals, which can then oxidize the NO to nitrogen dioxide (NO_2) and water-soluble species (HNO_2 and HNO_3). These water-soluble species are then scrubbed, resulting in a nitrogen-rich waste stream that can be sent to a treatment facility or used as a commercial fertilizer additive. A data acquisition system with LabView software is used for system controls, data recording at key points, and automated emergency shutdown.

Phase I used thermal activation by injecting H_2O_2 into the flue gas stream at an optimum temperature of about 930 degrees Fahrenheit (°F). Since the KSC boiler breech exhaust gas temperature was 340 °F, an inline natural gas burner was added to raise the temperature at the H_2O_2 injection point to simulate other sources. Phase I data confirmed conversion values above 90 percent for NO to NO_2 and water-soluble species (HNO_2 and HNO_3) using molar ratios of H_2O_2:NO slightly above 1.0. The H_2O_2:NO ratio is economically crucial for the commercial application of this method.

Phase II used ultraviolet (UV) radiation for activation of H_2O_2 so lower flue gas temperatures (400 °F) could be used at the injection point. The scrubber was also modified to improve scrubber pH and temperature control and to increase system capture of NO_2. The results were inconclusive; however, further testing is planned in Phase III key milestones.

Phase III implements (1) a 3000-watt, 2450-megahertz (MHz) microwave unit designed, built, and installed by Litton Systems, Inc., Electron Device Division, to activate the H_2O_2 in place of the UV unit and (2) an innovative experimental piping system design to make it easier to achieve the desired temperature in the reactor. The microwave idea and technology were introduced to the project by Tiberian Technologies, a new industrial partner in Phase III. The temperature parameter was controlled via a flue gas mixture from the boiler breech and combustion chamber to achieve the nominally required 400 °F reactor inlet temperature. Figure 1 shows the Phase III design configuration.

While Phase III modifications were in progress, Dynacs KSC Digital Media Laboratory designed and completed a simulation module that can be presented in multimedia formats depicting the conceptual application of the NO_X emission controls. This presentation format can be used in commercial marketing of this technology (figure 2).

Key accomplishments:

- 1997: Completed Phase I design, installation, and preliminary testing.
- 1998: Completed Phase I testing, data analysis, and reports. Presentations at the Air and Waste Management Association's (AWMA's) section meetings.
- 1999: Completed Phase II design, testing, data analysis, and reports. Presentations given at the AWMA Annual Conference and AWMA Florida section meeting. Modified system and reran short grouping of Phase I level tests for repeatability verification and speciation studies.
- 2000: Completed Phase III design and installation. Presentation given at the American Institute of Chemical Engineers Annual Conference. Developed 3-D computer rendering of

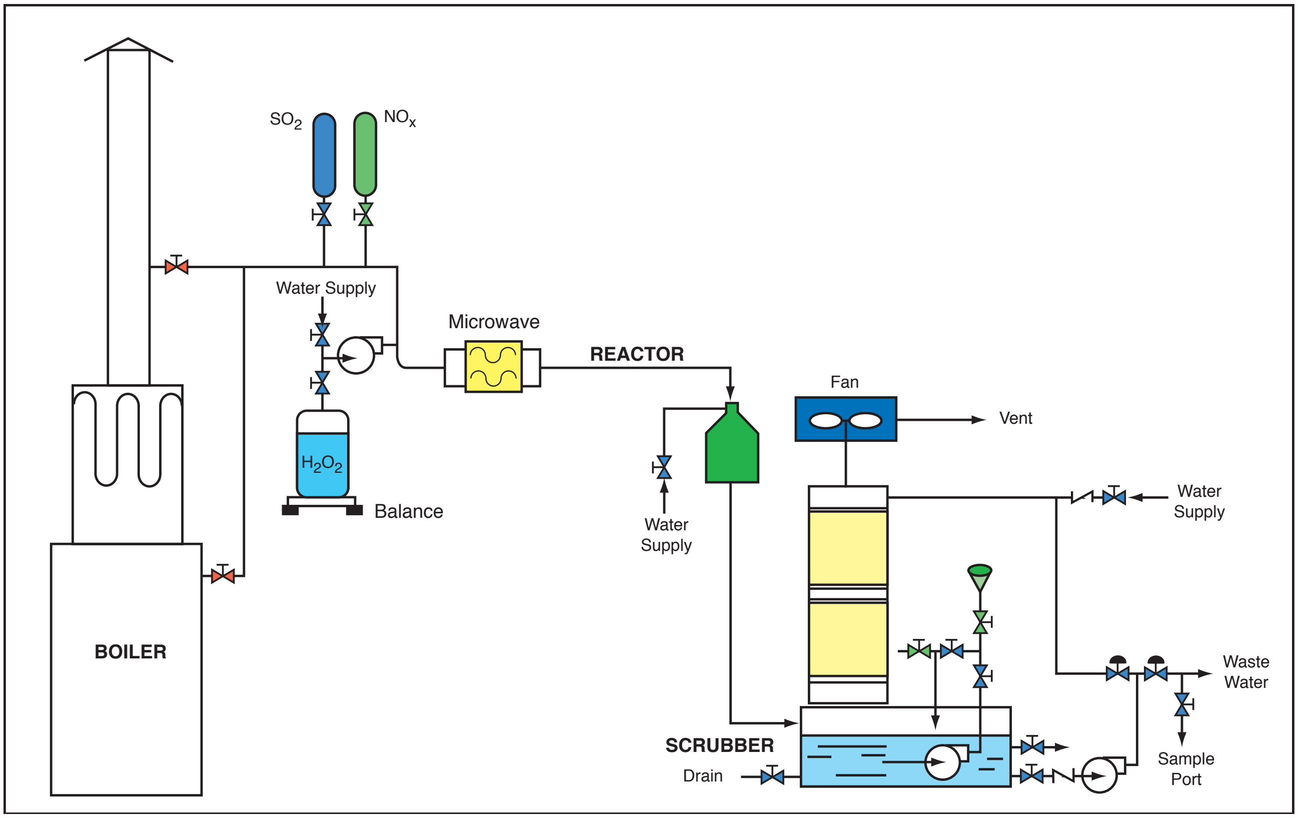

Figure 1. Phase III Schematic

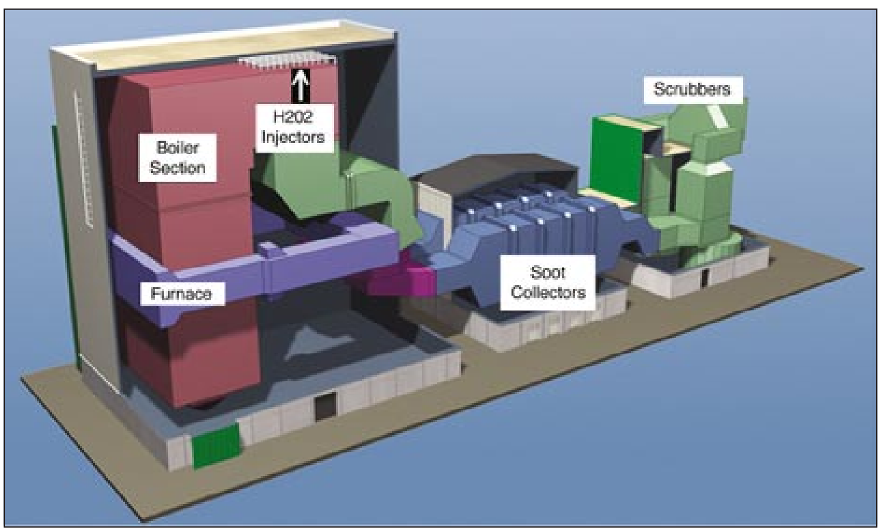

Figure 2. Conceptual Application of NO_x Controls

a proposed installation of the NO_x control system in a typical power plant.

Key milestones:

- 2001: Phase III testing, data analysis, reports, and presentations at technical forums. Further Phase II testing using the UV unit and modified scrubber using new scrubber liquor technology (see KSC Research and Technology 1998 Annual Report, "Installation of a New Scrubber Liquor for the Nitrogen Tetroxide Scrubbers That Produces a Commercial Fertilizer").

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Participating Organizations: University of Central Florida (Dr. C.D. Cooper and Dr. C.A. Clausen, III), Florida Institute of Technology (Dr. M. Pozo de Fernandez), EKA Chemicals, Inc. (J. Tenney and D. Bonislawski), Tiberian Technologies (S. Beers and A. Gravitt), Litton Systems, Inc., Electron Device Division (G. Schaeffer), and Dynacs Inc. (C.R. Nelson)

Earth Systems Modeling and Landscape Management

Land management practices in many ecosystems, including KSC, are based on controlled burning for habitat maintenance and reduction of wildland fuels. Available ecosystem models and fire and smoke models provide some guidance; however, no system exists that incorporates these tools with operational schedules such as payloads, vehicle processing, current meteorological data, and remotely sensed data for use in decision support and risk assessment.

The approach involves development of a diverse set of information tools including rule-based expert systems, numerical models, time series analysis, and fusion of a variety of data collection systems and databases such as fire prescriptions and fuels data, ecological and fire models, real-time meteorological data, and high-resolution aerial imagery. The project will:

- Provide data and information to optimize the management of resources at KSC and the Merritt Island National Wildlife Refuge.

- Incorporate NASA remote sensing and advanced Geographic Information System (GIS) technology into local scale decisionmaking processes.

- Provide information and methods to reduce the potential for wildfires at KSC.

- Enhance NASA capabilities to comply with Federal and state environmental laws such as the Endangered Species Act.

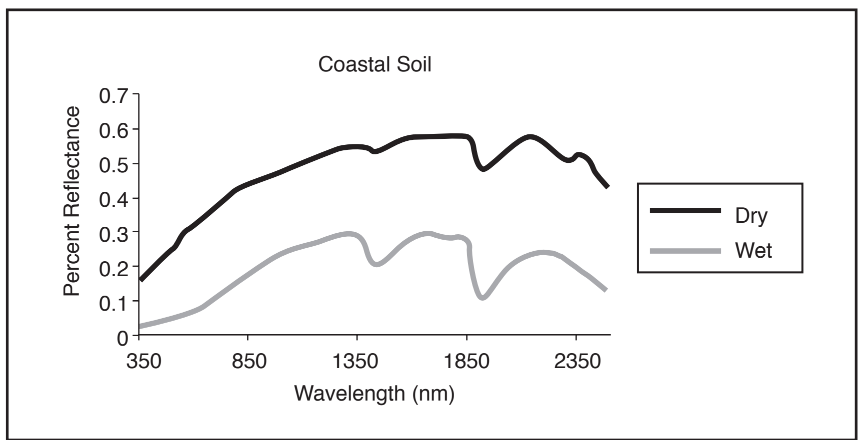
Key accomplishments:

- 1996: Obtained a high spectral resolution image of the KSC area using the NASA Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) sensor. Initiated development of a deterministic model for estimating plant canopy biochemical and biophysical characteristics.
- 1997: Conducted an experimental controlled burn at KSC in association with the U.S. Fish and Wildlife Service (USFWS), Los Alamos National Laboratory, U.S. Air Force, and Los Angeles County Fire Department to develop data on fire spread, intensity, and smoke production. Obtained high spatial resolution images (1 to 2 meters) of the KSC area. Obtained field measurements of plant canopy biophysical and biochemical features and plant canopy and leaf spectral characteristics for model development and parameterization.
- 1998: Initiated development of a Web-based decision support tool that integrates payload schedules, Shuttle operations schedules, facility locations, and controlled burn prescriptions to minimize conflicts and maximize management of wildland fuels and wildlife habitat. Integrated plant biophysical features such as leaf area, leaf angle distribution, canopy closure, canopy height, and bottom reflectance into a two-flow irradiance model for radiative transfer in plant canopies.
- 1999: Enhanced fire management information development and transfer with the Fire Management and Analysis Network (FireMAN). Acquired high-resolution Light Interferometric Detection and Ranging (LIDAR) data for development of a three-dimensional landscape model.
- 2000: Conducted radiometric analysis of plant and soil moisture content. Acquired base-wide high-resolution color infrared orthophotography. Generated three-dimensional virtual landscapes in GIS. Initiated development of a high-resolution fire-weather information system.

Key milestones:

- 1996: Initiated GIS database integration in ORACLE and development of image processing methods for the use of high-resolution data in wildlife habitat mapping.
- 1996: Presented two papers at the Eco-Informa Conference in Orlando, Florida, on remote sensing modeling in plant canopies.
- 1997: Coordinated a multiagency experimental controlled burn to obtain data on fire and smoke behavior in coastal environments.
- 1998: Enhanced communications between USFWS and NASA Shuttle and Payloads Operations through development of a Web-based sup-

High-Fidelity Spatial Model Derived From LIDAR, Aerial Photography, Virtual Objects (Trees), and Planimetrics (Buildings) (Observer Is Looking Southeast Toward the O&C Building and KSC Headquarters)



Radiometric Analysis Reveals Differences in Spectral Characteristics of Soils in Relation to Moisture Content

port system for controlled burns at KSC.

- 1999: Initiated a multiagency effort to support fire management and response activities with NASA, the U.S. Air Force, County Emergency Management, and the Florida Division of Forestry.
- 2000: Incorporated high-resolution, three-dimensional/rapid time series data into operational applications.

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Participating Organization: Dynamac Corporation (R. Schaub and C.R. Hall)

Threatened and Endangered Species Monitoring

The biological diversity of KSC is greater than that of nearly all other Federal facilities. Under the Endangered Species Act and the National Environmental Policy Act, operations require evaluation and impact minimization. Approximately 100 wildlife species at KSC and the associated Merritt Island National Wildlife Refuge are species of conservation concern. Monitoring focuses on combining field and remote sensing data with predictive/interpretive models on marine turtles, gopher tortoises, indigo snakes, wading birds, shorebirds, scrub jays, beach mice, and manatees. These studies contributed to more than 25 scientific journal articles and were used to develop rangewide species recovery efforts.

The influences of habitat features on abundance and demographic success are quantified at different spatial scales. Sequences of aerial photography are used to investigate how different land use practices influence habitat suitability and population parameters. Simulation models are used to quantify the influence of land use, habitat quality, population size, and catastrophes on populations. The studies are currently being applied across larger geographic areas through collaborative arrangements with other agencies and private foundations. Most studies are focused on Central Florida's Atlantic Coast. However, one study area ranges from San Francisco to Baja in order to support NASA environmental management concerns at Vandenberg Air Force Base, California. Results show launch effects are insignificant compared to larger scale ecosystem and population processes that need to be considered more carefully. Collaboration with an international team of scientists was also conducted to review similar approaches worldwide for purposes of summarizing the state of the science and knowledge gaps that prevent greater application of population modeling techniques. The results were summarized for a book on landscape ecology and biological conservation.

The table provides a validation of Florida scrub jay demographic predictions based on KSC studies. The table shows trends in the number of breeding pairs on the mainland in South Brevard County. Most territories were tall or irregularly burned except at the Sebastian Buffer Reserve, where there has been frequent fire. Valkaria also has much tall scrub, but colorbanding studies show population declines were buffered by immigration. Studies of large-scale population processes show jays have greater propensities to move from small fragments into larger fragments, such as Valkaria. These studies also show recolonization of restored scrub is influenced by the reluctance of male Florida scrub jays to move great distances. Therefore, the spatial and temporal implementation of restoration strategies must consider habitat potential and the existing population distribution. Knowledge gained by restoration strategies at KSC and on the mainland will be complimentary because the replication of a restoration across a range of different landscape arrangements and land use histories will enhance the ability to predict and interpret results.

Figure 1 represents one possible Markov chain model for scrub habitat dynamics at KSC by assuming current fire management will continue. The boxes represent four classes of Florida scrub jay territories (25-acre landscape units). The annual transition probabilities are calculated for several Florida scrub jay population centers at KSC. Only the "short and optimal mix" territory class has reproductive success rates that exceed the mortality rates. These population sources can sustain a portion of the scrub jay population residing in suboptimal habitat (the three other territory classes). Minimizing extensive population decline requires increasing the proportion of

Breeding Pairs of Scrub Jay on the Mainland in South Brevard County

Location	1993	2000
South Beach Conservation Areas and Habitat Fragments	26	5
Malabar Scrub Sanctuary	10	2
Jordan Sanctuary and Mitigation Areas	24	9
Valkaria Scrub Sanctuary	24	22
Babcock Mitigation Area	7	1
Micco Scrub Sanctuary	15	3
Palm Bay Habitat Fragments	53	18
Sebastian Buffer Reserve	11	11
Totals	170	71

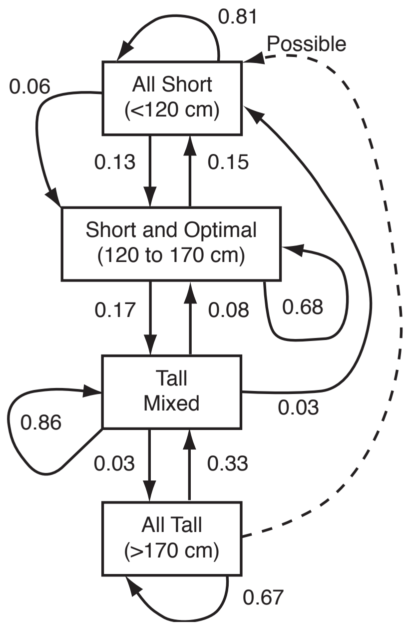

Figure 1. Markov Chain Model

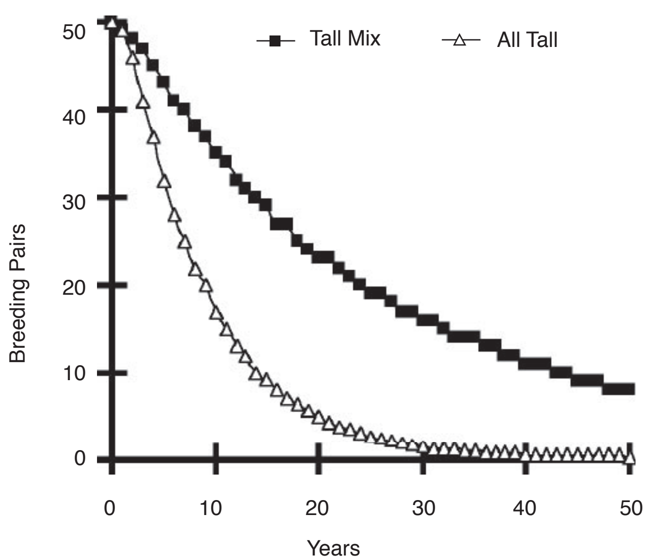

Figure 2. Predicted Population Trends Based on Habitat Quality

habitat composed of a mixture of short and optimal-height scrub at the appropriate spatial scale.

Figure 2 shows Monte Carlo simulations of data on birth and death processes collected from Florida scrub jay families that reside in territories at KSC that were composed of a mixture of tall scrub or scrub that had not been burned for a long period.

Key accomplishments:

- 1991: Developed habitat maps of the most important areas at KSC for scrub jays, wading birds, and other species.
- 1992: Developed a scrub restoration and monitoring program.
- 1993: Developed a wetlands restoration program plan.
- 1994: Developed a KSC biological diversity evaluation summary.
- 1995: Developed techniques to map habitat suitability.
- 1996: Developed models to predict demographic success using maps.
- 1997: Tested the ability of maps and models to predict populations.
- 1998: Developed rapid assessment tools for environmental managers.
- 1999: Developed procedures to incorporate uncertainty into decisionmaking.
- 2000: Developed procedures to project landscape changes.

Key milestones:

- 1995: Summarized population and habitat status trends for gopher tortoises, wading birds, and scrub jays.
- 1996: Developed a scrub jay population recovery strategy.
- 1997: Published biological diversity prioritization analyses.
- 1998: Published habitat analysis procedures.
- 1999: Published population risk modeling procedures.
- 2000: Expanded studies to investigate larger-scale population processes.

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Participating Organization: Dynamac Corporation (D.R. Breininger)

Plant Lighting Systems

Plants use visible irradiance as an energy source to produce food through photosynthesis for space inhabitants. The low electric power conversion efficiencies demonstrated by conventional lighting technologies would be prohibitive to growing plants on a large scale in space. Hence, current lighting research for space-based plant culture is focused on development of advanced lighting technologies that have a high electrical efficiency and appropriate spectral output for photomorphogenic requirements. Accordingly, light-emitting diodes (LED's) and microwave lamps are promising technologies being developed to efficiently generate photosynthetic radiation. LED's can illuminate near the peak light absorption regions of chlorophyll while producing virtually no near-infrared radiation. The sulfur-microwave electrode-less high-intensity discharge (HID) lamp uses microwave energy to excite sulfur and argon, which produces a bright continuous broad-spectrum white light. Compared to conventional broad-spectrum sources, the microwave lamp is highly efficient and produces limited amounts of ultraviolet (UV) and infrared radiation. The work in the KSC Life Sciences Support Program in association with the Johnson Space Center Advanced Life Support (ALS) Program gives insight into the feasibility of using LED's and/or microwave lamps as innovative alternative light sources for plant biomass production.

Within the ALS Program, salad-type plants represent crops that could provide a portion of fresh food as well as psychological benefits to the crew aboard future space transportation vehicles. Laboratory data generated with salad-type crops in the presence of various lighting sources will provide important information for modeling and development for future missions. Work was completed with spinach, radish, and lettuce plants grown in the presence of 9 different lighting sources for 28 days with different photoperiods. Three lamp banks represented broad-spectrum white light sources (microwave, high-pressure sodium, and cool-white fluorescent). Current testing also includes six separate LED arrays filled with a given wavelength of red [664, 666, 676, 688, 704, and 735 nanometers (nm)] LED's. Each LED array contains single rows of blue LED's (474 nm) evenly distributed within the multiple rows of red LED's.

Key accomplishments:

- 1998: NASA NRA Solicitation 98-HEDS-01 grant to Dynamac Corporation for salad-type plant lighting research. Published four research papers on lighting research findings with LED's.
- 1999: Began experiments with salad-type plant growth with LED's and microwave lamps.
- 2000: Completed initial salad-type plant growth studies with LED's and microwave lamps. NASA NRA Solicitation 98-HEDS-01 grant to Dynamac Corporation extended through 2001.

Key milestone:

- 2001: Complete testing of expanded salad crop list with LED's, sulfur-microwave, and conventional lighting technologies.

Root Zone of Radish Plants Growing in a Hydroponic Culture System Located Under a Sulfer-Microwave HID Lamp

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Participating Organization: Dynamac Corporation (Dr. G.D. Goins)

Candidate Crop Evaluation for Advanced Life Support and Gravitational Biology and Ecology

The primary objective of this task is to define the environmental conditions and horticultural methods to optimize edible biomass production and life support functions in candidate crop species. Environmental conditions include carbon dioxide (CO_2) concentration, light quality and quantity, temperature, relative humidity, and nutrient media elemental concentrations. An important consideration of this task involves screening different cultivars (cv.) of candidate crops and the compilation of crop growth data for inclusion in a crop handbook. This effort uses a standardized testing procedure for crop species recommended by a panel of plant scientists who met at KSC in May 1997. Development of crop management strategies for reuse of nutrient solutions with a special emphasis on biologically active organic materials that may accumulate in the nutrient solution is being addressed. This includes the coordination of NASA-supported tasks at the New Jersey NASA-Specialized Center of Research and Training (NJNSCORT) with tomato and salad crops; Tuskegee University with peanut and sweetpotato; Utah State University with wheat, rice, and soybean; and NASA Research Announcement (NRA) grant recipients for other candidate crops. Other significant collaborations include Cornell University on studies with dry bean, snap bean, and spinach.

The development of a bioregenerative life support system requires that the horticultural methodologies and the range of suitable environmental conditions for various candidate crops be well understood. In order to maximize the benefit to the Advanced Life Support (ALS) Program, this is an integrated activity requiring coordination with several research organizations and ongoing ALS tasks.

The candidate crop research conducted at KSC during 2000 included:

- Beans: Full life-cycle tests examining the growth and yield characteristics of both dry beans (cv. Etna) and snap beans (cv. Hystyle) at CO_2 concentrations of 400, 1,200, 4,000, 8,000, and 16,000 parts per million (ppm) were completed. This effort was in collaboration with Cornell University and Tuskegee University.

- Spinach, radish, and lettuce: Tests were conducted that measured photosynthetic efficiency and photomorphogenic response of these salad crops in the presence of narrow- and broad-spectrum lighting emissions from various lamp technologies. Lamps tested included light-emitting diode (LED), sulfur-microwave, fluorescent, and high-pressure sodium (HPS). These plant growth studies were completed in collaboration with the ALS Program, the KSC's Center Director's Discretionary Fund, the NRA grant to Dynamac Corporation, and several universities.

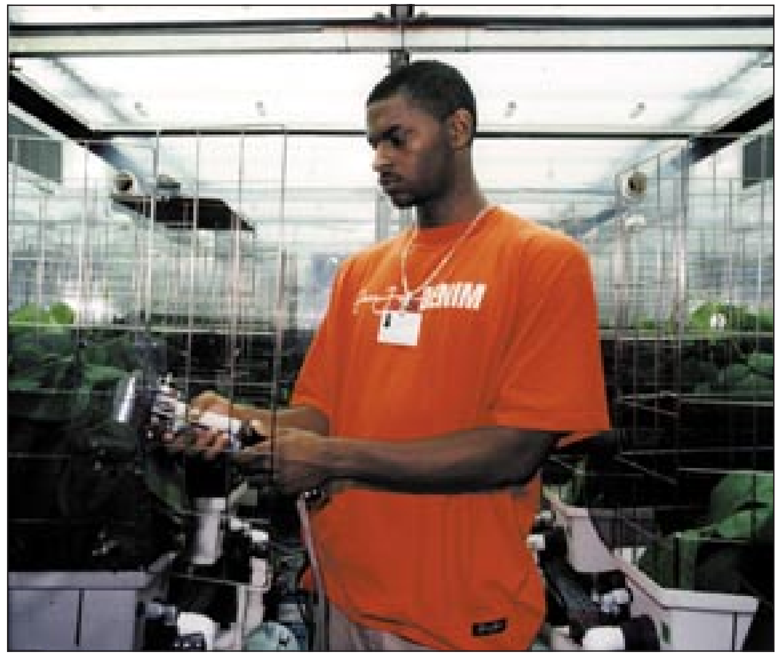
- White potato: Tests were conducted to determine management approaches for reuse of hydroponic nutrient solutions for successive generations of potato crops. Large-scale production of potato was maintained to further characterize a tuber-inducing factor that accumulates in hydroponic nutrient solutions.

- Wheat: Tests were conducted in collaboration with the resource-recovery/water-recovery task to determine the effect of different surfactant-based gray water on the vegetative growth of wheat. In addition, tests investigating the effects of using recovered nutrients from leached fresh or oven-dried composted inedible wheat biomass were completed.

Key accomplishments:

- 1999: Completed experiments investigating the effects on the growth of wheat by additions of leachates to composted inedible wheat biomass to the hydroponic nutrient solutions. Completed experiments investigating the dose-response of gray water (Igepon) on the growth and yield of wheat.
- 2000: Completed experiments investigating the

effects of super-elevated CO_2 on the growth and stomatal conductance of bean. Completed experiments investigating the effects of growing wheat hydroponically on recovered nutrients from fresh or oven-dried compost leachates. Completed experiments investigating the growth and yield of wheat on anionic, nonionic, and amphoteric surfactants. Defined crop-testing objectives consistent with near-term Mars mission scenarios with the ALS BIO-Plex Salad Crop Tiger Team. Nine peer-reviewed manuscripts, two book chapters, and seven NASA Technical Memoranda were published.



Joseph Anfield of Tuskegee University Performs Stomatal Conductance Measurements on Beans Grown at 8,000 ppm CO_2 as Part of a Collaborative Effort With NASA

Key milestones:

- 2001: First edition of the crop handbook for ALS candidate crops. Completion of tests examining the effects of super-elevated CO_2 on the growth and stomatal conductance of bean, lettuce, and radish. Completion of onion and radish cultivar evaluation as part of the salad crop inclusion in the BIO-Plex.
- 2002: Completion of tests investigating the environmental responses of onion and radish to define crop requirements for the BIO-Plex. Preintegration testing of other salad crop species for the BIO-Plex.

Dr. Gregory Goins of Dynamac Corporation Examines Hydroponically Grown Lettuce Plants That Were Produced With the Newly Developed Sulfur-Microwave Lamp

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Participating Organizations: Dynamac Corporation (Dr. G.W. Stutte, Dr. G.D. Goins, and N.C. Yorio), Utah State University (Dr. B. Bugbee), Cornell University (D. DeVilliers, C.F. Johnson, and Dr. R.L. Langhans), Rutgers University (Dr. H. Janes), and Tuskegee University (Dr. D. Mortley and J. Anfield)

Impact of Elevated Carbon Dioxide on a Florida Scrub Oak Ecosystem

Rising atmospheric carbon dioxide (CO_2) has the potential to stimulate carbon accumulation in ecosystems through direct effects on photosynthesis and growth of plants. It is not clear if in the long term (years to decades) CO_2 stimulation of plant growth would add significant amounts of anthropogenic carbon (either as woody tissue or soil carbon) to ecosystems (removing it from the atmosphere) because growth of native species is often limited by the supply of water and nutrients, particularly nitrogen. This is an important question in determining whether there will be an acclimation of natural ecosystems to rising atmospheric CO_2. It is also a fundamental question in evaluating global climate change. In 1990, KSC and the Smithsonian Environmental Research Center conducted a pilot study to evaluate the feasibility of research on these fundamental questions within the Florida scrub oak ecosystem at KSC. The success of that pilot study resulted in a proposal that was funded by the Department of Energy to set up a field study site at KSC. Since May 1996, 16 open-top chambers (see figure 1) have been operated in a scrub oak ecosystem at KSC at normal ambient or elevated (normal ambient plus 350 parts per million) atmospheric CO_2. After 2-1/2 years, the combined effect of elevated CO_2 on shoots, roots, microbial biomass, and soil carbon yielded a stimulation of 500 grams per square meter in ecosystem carbon.

Results of the research to date were reported in 17 scientific papers (with an additional 14 in review) and presented at numerous national and international meetings. Over the next 3 years, the study will focus on:

- Physiological responses and acclimation to high CO_2
- Growth in roots and shoots
- Effects of CO_2 on the plant and ecosystem water balance
- Source of nitrogen required to supply the approximately 80-percent stimulation of new plant growth
- Net ecosystem carbon assimilation by using the large open-top chamber (see figure 2) as a gas exchange cuvette
- Measurement of ecosystem gas exchange in the chambers exposed to normal ambient CO_2 with the net ecosystem gas exchange determined by eddy flux measurements
- Construction of a carbon budget based on ecosystem gas flux and the pools of carbon in plants, microbes, and soil

The Florida scrub oak ecosystem at KSC has a number of unique features as a study site for determining the impacts of elevated atmospheric CO_2:

- The fire return cycle in Florida scrub is about 10 years.
- This system is about to enter a canopy closure.
- The major oaks are clonal, permitting environment x genotype experiments.
- Scrub oak is low in stature permitting many replications.
- This ecosystem is subtropical and metabolically active.
- This system has all the essential elements of forest ecosystems: a large woody component, deciduous leaves, perennial growth, a large below-ground biomass, and a mature nutrient cycle with root closure.

The work to date indicates the scrub oak ecosystem responded vigorously to the elevated CO_2 treatment since the outset of the study in May 1996. A large stimulation of growth was expected after the site was initiated following a controlled burn; and this has happened – rising from 44 percent the first year to nearly 80 percent for both shoot and fine-root biomass the fourth year. On the other hand, the reduction of evapotranspiration with a consequent increase in soil water was a surprise, as was the magnitude of the increase in the standing crop of nitrogen in the biomass. While the source of water has been identified (using stable isotopes) as being primarily ground water, the source of

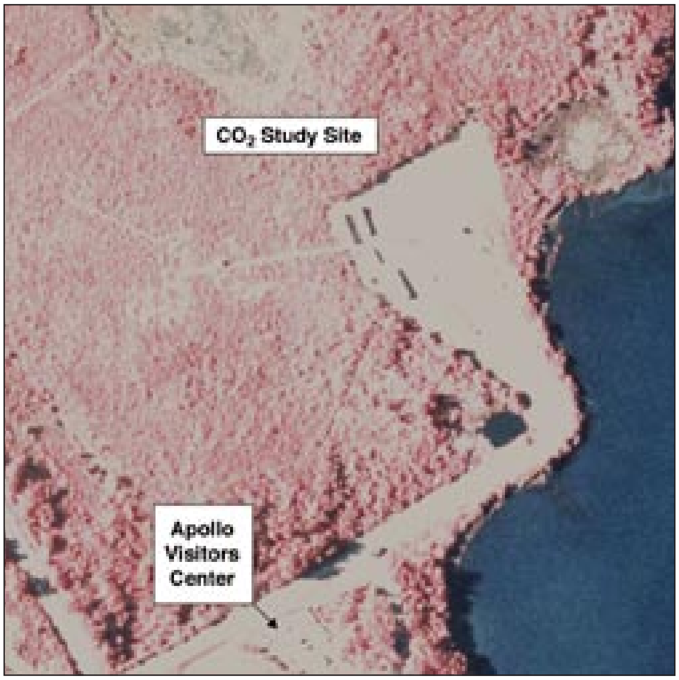

Figure 1. Location of the Elevated CO_2 Study Site Near the Apollo Visitors Center East of State Road 3 (The Board Walk, 16 Chambers, and Support Trailers Are Visible in This Orthophoto)

Figure 2. Open-Top Chambers at KSC

the additional nitrogen needed to supply the large stimulation in the biomass of shoots and roots has yet to be determined. Support for this project comes from NASA, the Mellon Foundation, the National Science Foundation, the Smithsonian Institution, and the Department of Energy.

The main effects of elevated atmospheric CO_2 are:

- Acclimation of photosynthesis in subdominants *Q. geminata* and *Q. chapmanii* but not in dominant species, *Q. myrtifolia*; small reduction (17 percent) in respiration per unit biomass.
- Stimulation of growth of shoots increased from 44 percent in 1996 to 75 percent in 1999; increased growth of roots 80 percent in 1998.
- Relatively smaller stimulation of leaf area (15 to 30 percent) than shoot biomass.
- Stimulation of net ecosystem gas exchange by 200 percent in 1996 reduced to 70 percent in 1999; increased ecosystem respiration per unit of ground area.
- Reduced stomatal conductance, stem flow, and evapotranspiration; increased volumetric soil water.
- Increased nitrogen fixation by increased growth of legume, *Gallactia Elliottii*.
- Total ecosystem carbon increased 500 grams per meter squared, primarily in fine roots.

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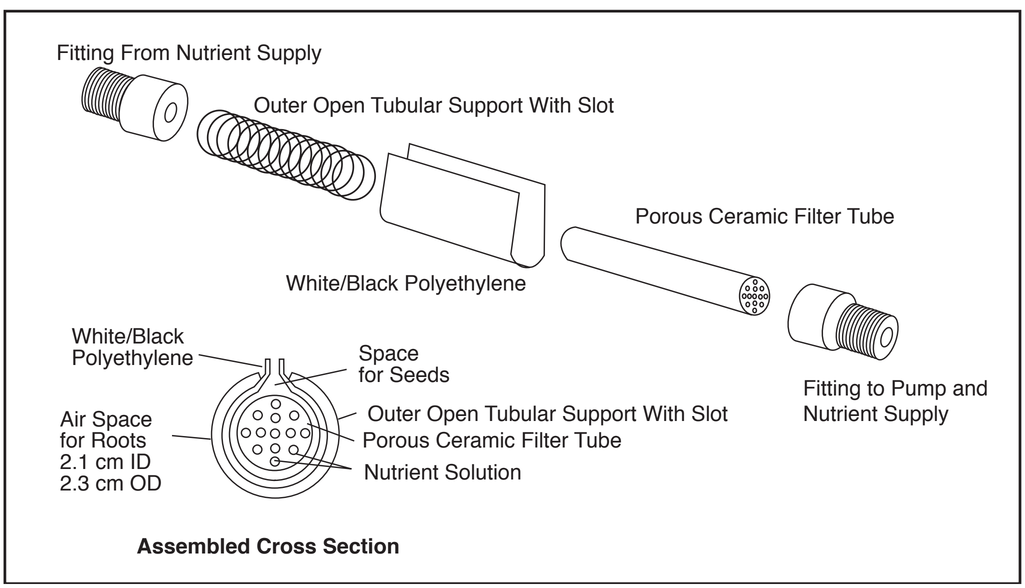
Participating Organizations: Smithsonian Institution (Dr. B.G. Drake, Dr. G. Hymus, Dr. J. Li, D. Johnson, and T. Snead), Old Dominion University (Dr. F. Day), Dynamac Corporation (Dr. R. Hinkle), Northern Arizona University (Dr. B. Hungate), University of Nevada at Reno (Dr. D. Johnson), University of Illinois (Dr. S.P. Long), Smithsonian Environmental Research Center (Dr. P. Megonigal), University of South Florida (Dr. P. Stiling), and NASA (Dr. S. Dore)

Ground-Based Testbed for Evaluating Plant Remote Sensing Technologies and Plant Physiological Responses to Stressors

Remote sensing methods for determining biomass, water status, photosynthetic rates, tissue chemical concentrations, and biophysical features of vegetation are recognized as important objectives for research in agriculture, terrestrial ecology, and earth system science. One problem facing plant researchers in these areas is the inability to precisely control the physiological status of test plants grown in conventional soil or hydroponic conditions. In addition, no system exists that will allow researchers to precisely control and monitor root water potentials, nutrients delivered, trace chemicals, toxic chemicals, or exposures in the case of toxicity testing. To address these issues, the patented Porous Tube Plant Nutrient Delivery System (PTPNDS) was integrated and expanded. The PTPNDS was previously developed at KSC to provide water and mineral nutrients to the roots of plants in microgravity.

The initial system that was constructed consists of 24 porous tube units, configured in three sets of eight tubes to allow for experimental replication of treatments. Each set is connected to a manifold that is connected to an individual standpipe to control the applied water potential (hydraulic pressure) of that set of tubes. The system was constructed within a controlled-environment chamber that controls temperature to within ±0.5 degree Celsius. Plant lighting consists of four to eight 400-watt metal fixtures providing approximately 350 to 700 micromoles per second per square meter at canopy height. The nutrient solution reservoir is a tank holding 100 liters of solution, which is pumped to the standpipes using a submersible pump. The flow of solution through the tubes is accomplished by a gravity siphon established at the downstream end of the tubes, which drain into a common drainpipe that returns the solution to the reservoir. In the current configuration, all the plants receive solution from a common reservoir. The standpipes are adjusted vertically to impose varying applied water potentials to the roots. Initially, as wide a range of water potentials as is practical will be imposed among the three levels. As data is obtained, continued studies will determine how small the difference can be and still be resolved by the instrumentation.



Construction and Components of the Microporous Tube System

Key accomplishments:

- 2000: Utilized materials on hand, existing facilities, and manpower provided by the Summer Industrial Fellowship for Teachers program to build the prototype system. Conducted an initial plant growth experiment to define system performance parameters utilizing wheat and radish as test crops. Submitted a proposal to the Florida Space Research Institute to obtain additional funding (the proposal was not selected for funding). Submitted a proposal to the Center Director's Discretionary Fund for funding. Submitted an abstract for presentation at the 2001 Florida Academy of Sciences annual meeting describing the system and initial data.

Radish and Wheat Plants Being Grown on the Porous Tube System

Key milestones:

- 2000: Constructed and tested the prototype system. Developed proposals to obtain funding.
- 2001: Develop a second-generation system for additional performance testing. Collect initial experimental data on plant physiology and remote sensing signatures. Publish or present results to the scientific community.
- 2002: Refine the system design and add additional monitoring, control, and data collection systems. Conduct additional experiments to characterize system performance utilizing native species and/or crop plants. Produce drawing of the tube system, photos of the system with plants, and the results of grow-out.

Average Percent Water Content of Plant Material From a Preliminary Study Using the Porous Tube System

Plant Part	Applied Water Potential	Percent Water
Radish bulbs	-5.0 cm H_2O	90.63
	-2.5 cm H_2O	91.18
	-0.5 cm H_2O	92.91
Radish roots	-5.0 cm H_2O	93.03
	-2.5 cm H_2O	93.81
	-0.5 cm H_2O	94.94
Radish tops	-5.0 cm H_2O	86.34
	-2.5 cm H_2O	87.03
	-0.5 cm H_2O	87.93
Wheat roots	-5.0 cm H_2O	93.61
	-2.5 cm H_2O	93.32
	-0.5 cm H_2O	99.50
Wheat tops	-5.0 cm H_2O	48.19
	-2.5 cm H_2O	52.84
	-0.5 cm H_2O	57.16

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Participating Organization: Dynamac Corporation (Dr. T.W. Dreschel and C. Hall)

Note: The plants were grown on three sets of eight tubes for 10 weeks at an applied water potential of -0.05 centimeter (cm) water (H_2O), and then the water potential on two sets was changed 2 weeks prior to harvest. In this case, the differences were not significant but indicated a possible trend. In future studies, plants will be cultured during the entire life cycle at different applied water potentials.

Survival of Terrestrial Microorganisms on Spacecraft Components and Analog Mars Soils Under Simulated Martian Conditions

Activities that are critical to the success of the Mars sample-return missions include modeling the microbial ecology of outbound spacecraft and predicting whether terrestrial microorganisms might survive and replicate on Mars. If terrestrial microorganisms present on spacecraft surfaces survive and replicate on Mars, then their presence on outbound spacecraft might affect the success of the sample-return missions. Several studies in the literature support the conclusion that microorganisms can easily survive in extraterrestrial environments if they are shielded from ultraviolet (UV) irradiation from the Sun. However, no studies have appeared in the literature that accurately simulated the survival of terrestrial microorganisms on spacecraft surfaces under realistic conditions of temperature, gas composition, pressure, and UV irradiation expected on Mars. Such information will be significant in the near future as spacecraft sanitation and processing procedures are developed for the 2003 and 2005 Mars landers.

The primary objective of this research is to develop an empirically derived model of the survival of terrestrial microorganisms (found on spacecraft surfaces) under robustly simulated Martian conditions in order to predict whether spacecraft contaminants will survive on Mars. Lethal dose rates (LD_{99}) of microorganisms will be calculated to predict the biocidal effects of UV irradiation on Mars for different landing sites and different mission scenarios. A second objective is to determine the minimum environmental conditions required for microbial replication on Mars. These results will be used to predict forward contamination risks to rover landing sites and Mars global environments. Research will test microbial survival under various conditions of UV irradiation, gas pressure, oxygen partial pressures, and dust layers under simulated Martian conditions. Experiments will be conducted in the Mars Simulation Chamber (MSC) operated by the Biological Sciences Branch of the Engineering and Science Division (see the figure).

The MSC is a stainless-steel low-pressure cylindrical chamber with internal dimensions measuring 1.5 meters in length by 1 meter in diameter. The MSC is configured with a liquid-nitrogen (LN_2) jacket within the chamber. The LN_2 jacket's primary function will be to reduce the thermal-loading from the external wall of the chamber and, thus, enhance the low-temperature control of experimental hardware assembled on the flat working surface of the chamber. Control of atmospheric pressure will be achieved by a solenoid-actuated control system connected to a bottled gas mixture that simulates the Martian atmosphere. Bottled gas mixtures will contain carbon dioxide (95.3 percent), nitrogen (2.7 percent), argon (1.7 percent), oxygen (0.2 percent), carbon monoxide (0.07 percent), and water (0.03 percent). The gas composition used in these experiments is based on the results of the two Viking missions.

Key accomplishments (2000):

- Design of a Mars normal UV-irradiation light source was completed. The UV light source will be installed on the MSC in the Operations and Checkout Building. The UV lighting system will produce a Mars normal spectrum (200 to 1200 nanometers) that will be delivered to the experimental hardware in the chamber through a series of fiber-optic bundles.
- Design and fabrication of several pieces of research equipment were completed. The research equipment will be used to control and modify the spectral quality of light striking spacecraft components within the MSC.
- Laboratory procedures for the growth, manipulation, and assay of bacterial species intended for this project were completed.

Key milestones (2001):

- All equipment will be installed within the MSC beginning in March.
- Experimental chamber calibration tests will be completed by May 1.

- Three experiments are scheduled:
  – Survival of the bacterium, Bacillus subtilis, on the surfaces of several spacecraft components
  – Effects of dust on the protection bacteria present on spacecraft at the time of landing on Mars
  – Effects of direct versus diffuse UV irradiation on bacterial survival on spacecraft components

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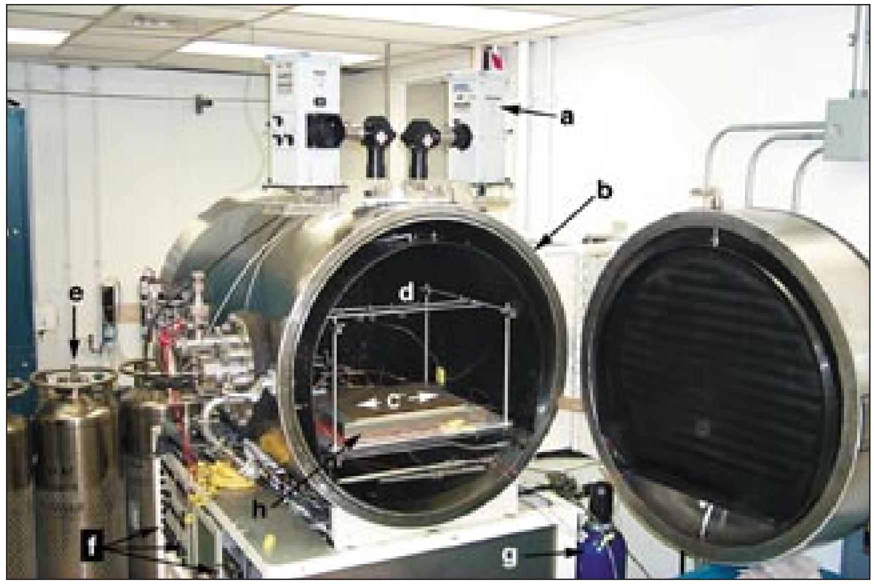

The Mars Simulation Chamber (MSC)

(a) Two 450-watt Xenon-arc lamps will be used to generate a Mars normal light environment including the production of high levels of UV light.
(b) The outer shell of the MSC.
(c) The bacterial samples are placed on this surface and exposed to Mars normal levels of pressure, gas composition, temperature, and UV light.
(d) The metal supports above the surface where the bacteria will be placed are used to support the fiber-optic bundles that will hang down from the top of the chamber. The fiber-optic bundles will collect light from the Xenon-arc lamps and direct it toward the bacteria sitting on item labeled "c."
(e) Liquid nitrogen is required to lower the temperature of the experiments to -85 °C (-121 °F) inside the chamber. This simulates the low temperatures encountered on Mars at night. The daytime highs for Mars are between -10 and +10 °C (around 20 to 45 °F).
(f) The Mars Simulation Chamber has an automatic control system that can be used to simulate a diversity of Mars surface conditions.
(g) The blue tank contains the "Mars gas" mix. It is composed of carbon dioxide (95.3%), nitrogen (2.7%), argon (1.6%), oxygen (0.13%), and water vapor (0.03%).
(h) The liquid nitrogen cold-plate uses liquid nitrogen from the tanks outside the chamber to accurately control temperature in the Mars Simulation Chamber.